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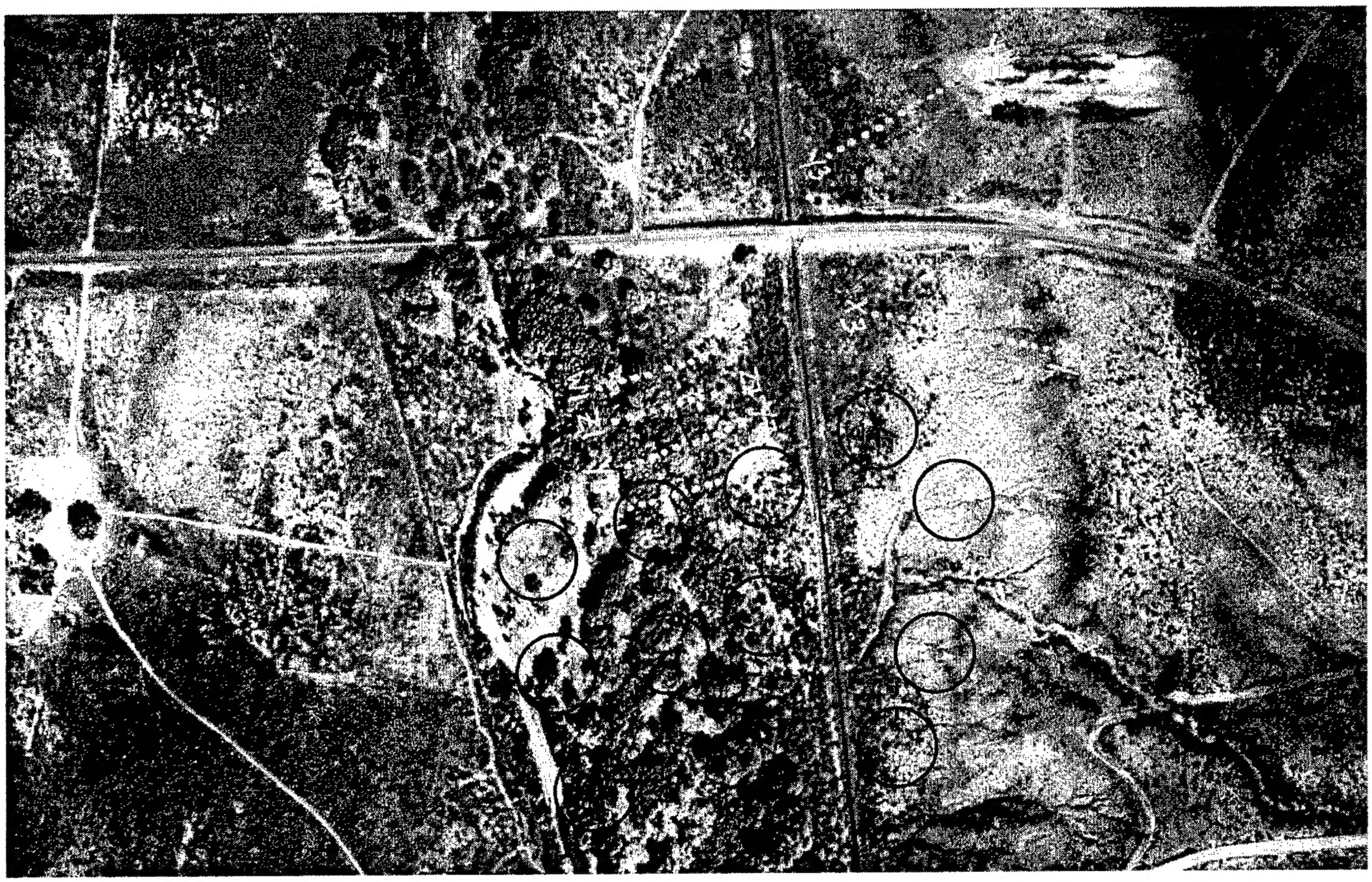
MODELING THE EFFECTS OF ECOSYSTEM FRAGMENTATION AND RESTORATION: MANAGEMENT MODELS FOR MOBILE ANIMALS

CS-1100

ANNUAL REPORT, FY 1998
01 December 1998



[San Pedro house riparian study site, Cochise County, Arizona.]

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)

2. REPORT DATE
01 December 1998

3. REPORT TYPE AND DATES COVERED
Annual Report FY 1998

4. TITLE AND SUBTITLE
Modeling the Effects of Ecosystem Fragmentation and Restoration: Management Models for Mobile Animals, CS-1100

5. FUNDING NUMBERS
N/A

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

8. PERFORMING ORGANIZATION REPORT NUMBER
N/A

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

SERDP
901 North Stuart St. Suite 303
Arlington, VA 22203

10. SPONSORING / MONITORING AGENCY REPORT NUMBER
N/A

11. SUPPLEMENTARY NOTES
This report presents results from the first year of research conducted under SERDP project CS-1100, Modeling the Effects of Ecosystem Fragmentation and Restoration: Management Models for Mobile Animals.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release: distribution is unlimited.

12b. DISTRIBUTION CODE
A

13. ABSTRACT *(Maximum 200 Words)*
Objectives of the proposed research include advances in theoretical and empirical ecology and the development of practical management models to guide landscape planning and habitat management in areas where operational objectives coincide with significant wildlife and natural area values. The proposed field research will elucidate relationships between landscape composition and the abundances of sensitive, threatened, and endangered species. Key questions include: What are the life history characteristics that determine the type and magnitude of a species' sensitivity to fragmentation and, more specifically, habitat edges and landscape boundaries; how do microclimatic factors change when a large block of suitable habitat is fragmented into several smaller blocks; Can the biologically significant aspects of habitat type and landscape composition be determined form remotely sensed data products?

Modeling efforts will build on connections between life history characteristics and the responses of mobile animals to habitat fragmentation and restoration. A 2nd phase of field research will test model predictions and refine the conceptual approach. Use of the validated landscape-scale models in management situations will allow management personnel to estimate and compare the effects of alternative management activities on species of special concern. By simulating the results of proposed activities, managers will be able to select activities that minimize or avoid altogether the negative impacts on sensitive species.

14. SUBJECT TERMS
endangered species — CS-1100
habitat fragmentation — SERDP
mobile animals — SERDP Collection

15. NUMBER OF PAGES
39

16. PRICE CODE N/A

17. SECURITY CLASSIFICATION OF REPORT
unclass.

18. SECURITY CLASSIFICATION OF THIS PAGE
unclass.

19. SECURITY CLASSIFICATION OF ABSTRACT
unclass.

20. LIMITATION OF ABSTRACT
UL

ABSTRACT

This report presents results from the first year of research conducted under SERDP project CS-1100, "Modeling the Effects of Ecosystem Fragmentation and Restoration: Management Models for Mobile Animals." We provide background on the project objectives and research approach. The bulk of the report documents project development over the 8-month period beginning late March 1998, when funding was available to the PI at Northern Arizona University, through 30 November 1998, as analysis continues on data collected during the first season of field research. Significant progress, detailing study design, sampling methods, and preliminary results is presented from five linked research initiatives:

1. Studies of Edge Responses of Birds in Desert Riparian Habitats
2. Studies of Edge Responses of Birds in Ponderosa Pine Forests
3. Studies of Edge Responses of Butterflies in Desert Riparian Habitats
4. Studies of Butterfly Distribution Across Edge Gradients in Ponderosa Pine Forests
5. Studies of Microclimatic Gradients Across Edges Associated with Ponderosa Pine Restoration

In addition, results from related research on applications of remotely sensed data in mapping animal habitats are discussed briefly, focusing on direct applications in the SERDP project. Future research plans are outlined, and extensive primary data sets are presented in a series of appendices.

BACKGROUND

The detrimental effects of habitat fragmentation on animal populations are widely documented and thoroughly appreciated in the management of sensitive, threatened, and endangered species (Whitcomb et al. 1981; Lynch and Whigham 1984; Wilcox and Murphy 1985; Robinson et al. 1995). In contrast, the development of practical tools to predict the effects of fragmentation and design appropriate mitigation efforts has progressed only slowly (Saunders et al 1991; Wiens 1995). This project seeks to develop species-specific models that predict the responses of mobile animal species in heterogeneous landscapes (Sisk and Margules 1993; Sisk et al. 1997). Working primarily in ponderosa pine forests and riparian habitats on and adjacent to military lands in Arizona, we will link field and remotely sensed data in landscape models that will permit comparison of the impacts of alternative land use strategies on wildlife species of management concern.

OBJECTIVES

Objectives of the proposed research include advances in theoretical and empirical ecology and the development of practical management models to guide landscape planning and habitat management in areas where operational objectives coincide with significant wildlife and natural area values. The proposed field research will elucidate relationships between landscape composition and the abundances of sensitive, threatened, and endangered species. Key questions include:

1) What are the life history characteristics that determine the type and magnitude of a species' sensitivity to fragmentation and, more specifically, habitat edges and landscape boundaries;
2) how do microclimatic factors change when a large block of suitable habitat is fragmented into several smaller blocks;
3) Can the biologically significant aspects of habitat type and landscape composition be determined from remotely sensed data products?

Modeling efforts will build on connections between life history characteristics and the responses of mobile animals to habitat fragmentation and restoration. A second phase of field research will test model predictions and refine the conceptual approach. Use of the validated landscape-scale models in management situations will allow management personnel to estimate and compare the effects of alternative management activities on species of special concern. By simulating the results of proposed activities, managers will be able to select activities that minimize or avoid altogether the negative impacts on sensitive species or, conversely, those that maximize the benefits of proposed habitat restoration or enhancement activities.

TECHNICAL APPROACH

As habitats have become increasingly fragmented by changing patterns of human land use, resource managers and conservation scientists have focused on the loss of habitat area and the increasing isolation of remnant patches (e.g., Harris 1984). Despite recent advances in understanding the general consequences of fragmentation on biological diversity, the development tools for predicting these impacts have progressed slowly. Models of habitat patches in isolation from the surrounding landscape have highlighted the shortcomings of applied island biogeographic theory (Saunders et al. 1991; Wiens 1995), and led ecologists to pursue more complex, spatially-explicit demographic models (e.g., Pulliam et al. 1992; Dunning et al. 1995). While some of these approaches have proven effective in applied conservation biology

(e.g., Noon and McKelvey 1996), their demand for massive amounts of field data make them impractical as day-to-day management tools. We are pursuing a middle course for modeling habitat fragmentation, fusing species-specific field data and community-level spatial models at the landscape scale.

Our approach for moving beyond the limitations of island models, while avoiding "data-hungry" demographic approaches, is to model landscape heterogeneity by weighting habitat quality according to species' responses to habitat edges (Sisk et al. 1997). One of the most pervasive effects of fragmentation is the exponential increase of edge habitat. As extensive habitat areas are split into one or more smaller patches, and as patches are impinged upon and deformed into odd shapes, edge habitat proliferates (Figure 1). In many cases, habitat edges introduce novel conditions, in the form of altered microclimates, changes in the accessible resource base, and introduction to predatory and/or competing species. In heterogeneous landscapes, edge effects have been shown to be an influence on habitat quality in remnant patches. Our approach to modeling animal habitat suitability in fragmented landscapes is based on the quantification of species-specific responses to edges and the projection of responses onto spatially-explicit habitat maps. This approach has been developed through a series of related research projects, described below. The proposed study will allow the refinement and full integration of these techniques, producing a general, operational product that will have immediate management applications. Measuring edge responses captures different underlying mechanisms, including both within-patch factors (such as floristic, structural, and microclimatic attributes) and external factors, such as the modifying influence of the surrounding matrix habitats. Treating edge responses as a surrogate for detailed behavioral and demographic mechanisms provides an efficient and effective approach to quantifying species' responses to habitat fragmentation.

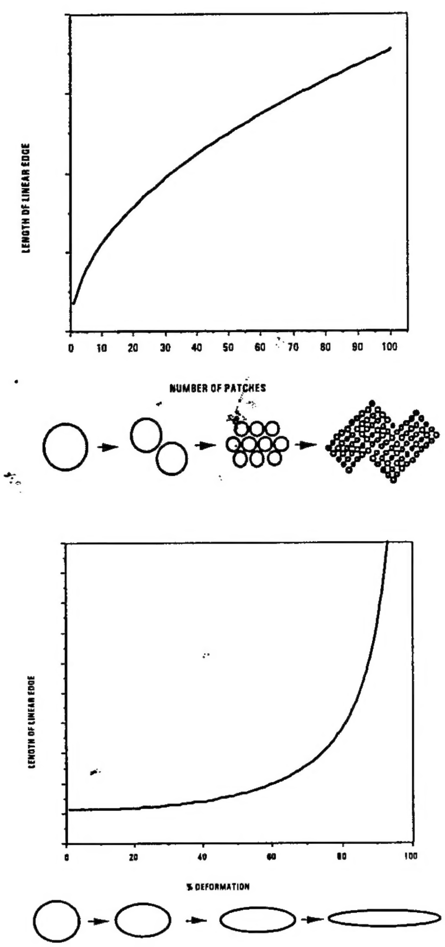


Figure 1. Edge habitat increases rapidly as previously contiguous areas are broken into smaller patches (above) that are typically irregularly shaped (below). Edges influence habitat quality in the resulting patches. [Adapted from Sisk and Margules 1993.]

Ecological Theory

Previous research on edge effects has assumed that population densities of some species will change as a function of the distance from the habitat edge; however, few authors have stated explicitly which species they expect to be influenced by habitat edges or how they will respond. Often, all species are assumed to behave similarly and/or exhibit a constant edge response, up to some arbitrary distance into the habitat patch (e.g., Laurance and Yensen 1991; Temple 1986). Moving beyond this simplistic framework for understanding edge effects requires a quantitative framework for characterizing species-specific responses efficiently and effectively. We have developed a classification scheme for population-level edge responses based on changes in density along a transect from one interior habitat, across the edge, and into the adjacent habitat (hereafter the edge gradient)

(Sisk 1992; Sisk and Margules 1993). We consider three classes of edge responses: edge exploiters, species that maintain elevated densities near the edge; edge avoiders, species that decline in density near the edge, even within seemingly suitable habitat; and species that exhibit no effect and whose changes in density along the edge gradient are attributable simply to differences between the two adjoining habitats (Figure 2).

We hypothesize that the actual response curves for each species in a community will resemble one of these models, although actual population densities will vary widely among species. Preliminary results support this hypothesis (see first-year results, below). Once edge responses are described for all species of concern, these responses can be used to characterize species-specific sensitivities to habitat fragmentation via spatially explicit projections of edge responses onto detailed landscape maps. Results from preliminary studies (Sisk et al. 1997; Sisk and Zook, *in prep.*) indicate that the approach provides significant improvement over simple habitat suitability models (USFWS 1981) and "core area" models that do not take into account the variability in edge responses (e.g., Temple and Cary 1988).

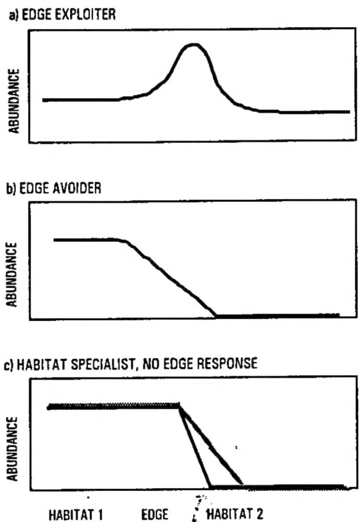


Figure 2. Hypothetical density responses for mobile animals species occurring near abrupt edges between different habitat types. [From Sisk and Margules, 1993.]

Field Studies of Edge Responses

Previous research has shown that species respond individualistically to habitat edges, and that in highly fragmented or heterogeneous landscapes, these edge responses can explain much of the variation in species abundances among patches (Szaro and Jakle 1985; Sisk et al. 1997). We quantify species-specific responses to habitat edges by estimating population density along a habitat gradient extending from the interior of one habitat, across the edge, and extending into the interior of the adjacent habitat (Noss 1991; Sisk and Margules 1993). Species-specific edge responses can then be empirically defined for the entire community or for species of management concern. Interestingly, previous empirical work (Sisk 1992) has shown that the edge response of a particular species may vary considerably at edges between different habitat types. For example, a woodland bird that is an edge exploiter at a boundary with grassland may be edge-avoiding at a shrubland edge (Sisk and Margules 1993). This suggests that it is an oversimplification to classify species as being simply edge or interior species. The effects of fragmentation are more complicated, and this complexity suggests that a general approach for predicting a species' sensitivity to habitat fragmentation is likely to require an in-depth examination of life history characteristics. To permit this detailed analysis of species:habitat responses near edges, we are collecting high-resolution data on microclimatic variation along the edge gradient (e.g., Ranney et al. 1991; Malcolm 1994), using automated monitoring systems to quantify ambient temperature, relative humidity, and solar radiation (see below).

We are focusing on breeding passerine birds and diurnal Lepidoptera at all study sites. Selection of both vertebrate and invertebrate taxa will provide a robust test of field and modeling approaches. These taxa offer particular advantages for fragmentation studies: both are speciose groups that are relatively easy to identify in the field; proven survey methods have been published; and their mobility suggests that they will respond rapidly to landscape change, permitting a relatively rapid turnaround from model development to field validation.

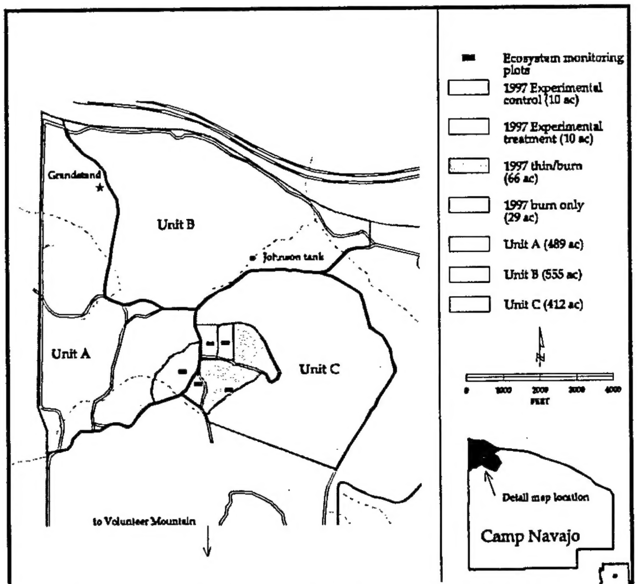
A central objective of the proposed study is to develop a mathematical characterization of edge responses. To date, we have focused on empirical data to characterize edge responses (see below). During the winter months, we will investigate alternative techniques to describe these responses as continuous functions. One approach is to treat animal abundance in a particular patch as a theoretical volume that could be solved by integration. There are advantages to a continuous approach: greater flexibility in defining the edge response, and potentially high precision in the patch-based estimates of animal abundance. If the approach is tractable, it may be possible to associate characteristic responses with particular life history traits, which would provide predictions of a species edge response without the exhaustive (and expensive) field surveys needed for empirical approaches. Field studies at several independent sites will facilitate evaluation of the continuous approach to characterizing edge responses.

Study Sites

Our proposed approach to studying biodiversity in changing landscapes is not restricted to particular sites or habitat types. To avoid site- or habitat-specific biases, field studies have been established in pine forests and riparian areas, two habitat types that are widespread throughout the country. Both hold particularly high value for biological diversity and face considerable conservation challenges.

Ponderosa pine forests are the subject of intense current debate regarding proper management objectives and techniques (Babbitt 1997; Covington et al. 1997). The suppression of wildfire since European settlement in the late 19th century has resulted in a shift form open, park-like forest stands to denser stands of small trees that are prone to catastrophic fire. The destructiveness of recent fires and the expense of fighting them has led Federal land managers to experiment with forest management practices designed to restore ponderosa pine stands to presettlement conditions (Covington et al 1997).

The primary ponderosa pine field sites for the proposed research will be Camp Navajo in north-central Arizona, operated by the U.S. Army and Arizona Army National Guard (Figure 3), and Mt. Trumbull on the north rim of the Grand Canyon, administered by the Department of the Interior. Experimental studies in the restoration of pre-settlement forest structure are underway at both sites. Over the next four years, mechanical thinning and prescribed burning will create abrupt edges with surrounding forest habitat, offering opportunities for true controls and replication of plots and transects across the landscape. An excellent vegetation data base is available for both sites (Fulé et al. 1995).



Figrue 3. Camp Navajo, primary field site for ponderosa pine habitats. The proposed research will be fully integrated with ongoing experiments in the restoration of native forest structure. [From Fulé et al. 1995.]

Additional ponderosa pine study sites will be established on the north and south rims of the Grand Canyon, where four experimental pine restoration plots have been proposed. These additional sites will provide opportunities for independent tests of the edge response characterizations from Camp Navajo and Mt. Trumbull, as well as the ability to conduct rigorous

field tests of predictions from landscape-scale models of animal abundances in managed landscapes.

Image from University of Arizona Office of Arid Land Studies

Figure 4. Primary riparian study sites will be located on Ft. Huachuca Military Reservation and nearby sites in the San Pedro River valley in southern Arizona.

Riparian habitats support the greatest biological diversity of any habitat in the western USA (Sampson and Knopf 1994) and, for this reason, they are the subject of intense conservation interest. The San Pedro River, flowing north from Mexico, is the last free-flowing river in Arizona (Figure 5). The Nature Conservancy has declared the San Pedro riparian corridor one of the "12 Last Great Places of the Western Hemisphere" in terms of ecological diversity and importance, and much of its course lies within a National Riparian Conservation Area. We propose to apply field and modeling approaches to riparian habitats along the San Pedro River, in conjunction with ongoing studies by the Wildlife Office of Ft. Huachuca's Environmental Division, and in cooperation with large, multidisciplinary science effort focusing on the San Pedro river basin – the Semi-Arid Land Surface-Atmosphere Program (SALSA). SALSA, supported by the U.S. Department of Agriculture, NASA and a consortium of seven federal agencies, 4 universities, and 5 foreign agencies, seeks to understand the consequences of natural- and human-induced change on the hydrology and ecological diversity of the San Pedro River Basin at event, seasonal, interannual, and decadal time scales.

The riparian component of the proposed research will benefit from cost-sharing of remote sensing data products and expertise, and association with SALSA will increase opportunities for implementing our landscape-scale ecological models. It also will help increase the profile of the SERDP program within the scientific community. The leader of the SALSA effort enthusiastically supports this proposal (see appended letter of support from Dr. David C. Goodrich). Intensive field work will take place on and near Ft. Huachuca, while extensive riparian habitats (both intact and fragmented) along the course of the San Pedro river will provide ample opportunities for evaluating the generality of edge responses and testing model predictions.

Mapping the Spatial Distribution of Habitat Types

Efforts to understand the effects of fragmentation on animal populations are constrained by the difficulty of obtaining detailed habitat information. Habitat maps typically are based on dominant plant species, however, habitat quality for many animal taxa depends not only on these floristic factors, but also on vegetation structure and the spatial arrangement of habitat types within the landscape (Wiens 1995). Current research by the Sisk lab (Imhoff et al. 1997; Hampton, in prep.) has demonstrated the potential for using Synthetic Aperture Radar (SAR) to discriminate between forest structural types (Figure 5).

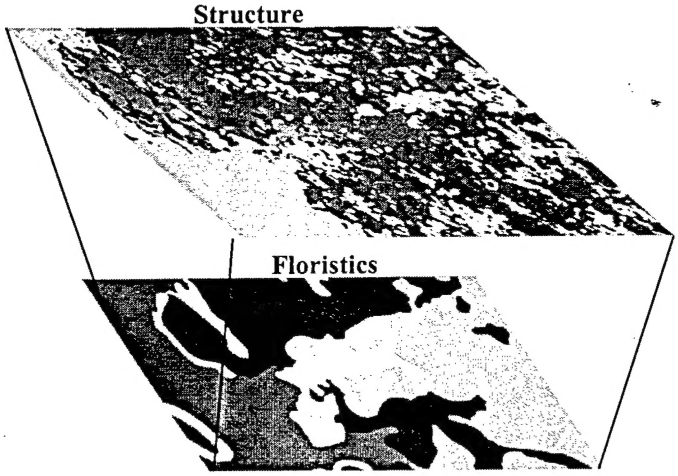


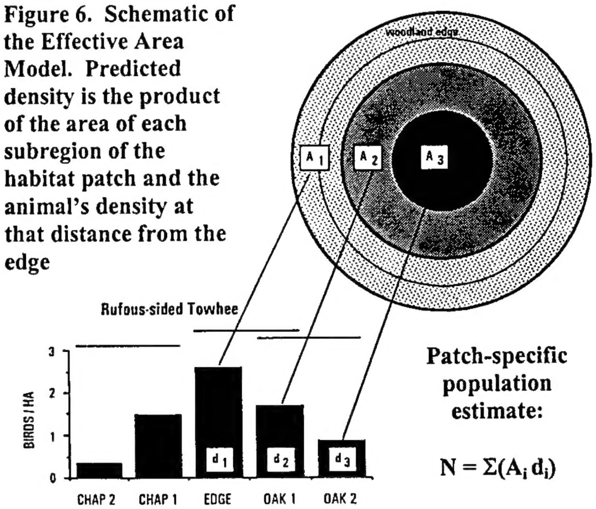
Figure 5. Work in the Sisk lab during the past year has advanced techniques for classifying multichannel Synthetic Aperture Radar data to generate maps of vegetation structure. Integration of structure and floristics data in a GIS can produce detailed maps of animal habitats (from Hampton, in

Recent progress has demonstrated the utility of combining radar data with aerial photography and/or Landsat imagery to generate remotely-sensed landscape maps that contain both structural *and* spatial determinants of habitat quality for many mobile animals (Figure 7). While most current habitat mapping efforts rely exclusively on remotely-sensed floristic attributes, our results support the approach for integrating radar, Landsat, and ecological field data to produce a more detailed map of wildlife habitat over large areas. The research conducted over the past year was supported by a NASA grant and, therefore, is not presented in detail in this report. However, this work is directly relevant to the SERDP project; we will pursue a similar approach in the ponderosa pine and riparian habitats of Arizona, with the goal of delineating structural differences among woody vegetation associations and mapping the edges between different floristic and structural types. This may permit accurate and ecologically meaningful mapping of bird and butterfly habitats over extensive areas.

The Effective Area Model

Despite broad recognition of the influence of edges on insular biota, edge effects have seldom been successfully applied in conservation and mitigation settings. A quantitative, predictive approach is needed before species-specific empirical data and detailed habitat maps can be used effectively to predict the impacts of habitat fragmentation. We have developed an empirically-based spatial model called the Effective Area Model (EAM) to test the influence of edge and matrix habitats on bird abundances, and to serve as a prototype for applying this information to real-world conservation planning (Sisk et al. 1997). The EAM uses two types of input data -- the edge response of each species of interest and a detailed landscape map -- to generate predictions of animal abundances in heterogeneous landscapes. The model projects species- and site-specific density estimates from the edge response curves onto digitized landscape maps, based on distance from the habitat edge (Figure 6). Model refinement and improvement is a major objective of this project; however, this has not been a primary focus during the first field season. Development will be guided by empirical results and familiarity with the study habitats. That work will begin during the coming winter, in preparation for trials during 1999. We will use ARC/INFO, the industry-standard GIS software, to develop GIS-based versions

Figure 6. Schematic of the Effective Area Model. Predicted density is the product of the area of each subregion of the habitat patch and the animal's density at that distance from the edge



of the Effective Area Model. Following field tests and refinements, the models will be designed to run in the user-friendly ArcView environment, allowing operational personnel to generate predictions of the effects of alternative management scenarios using PC or Macintosh platforms. The EAM will be used to predict the densities of sensitive species, as well as other species likely to influence their abundance, such as competitors, prey species, or predators. Model predictions will be tested with independent field data and the EAM's effectiveness for different taxa and different habitat types will be evaluated.

PROJECT ACCOMPLISHMENTS

The first year of the project involved initiation of several different field research efforts. These are reported below, with brief summaries of methods, first-year results, and preliminary conclusions addressing sampling design and directions for continuing efforts. While these projects are intimately linked with respect to the research approach presented above, the nature of the work dictates that the efforts be examined individually during the early stages of the research

Part I: Preliminary Findings from Studies of Edge Responses of Birds in Desert Riparian Habitats

Study Sites and Methods

This phase of the study was conducted during 1 June - 10 August, 1998 in the San Pedro National Conservation Area (SPNCA). The SPNCA is located in Cochise County in southeastern Arizona and is administered by the Bureau of Land Management. The conservation area extends from the United States / Mexico border northward approximately 40 miles (Map 1). There is a privately-owned, two-mile gap in the National Conservation Area (NCA) between Palominas and Hereford, Arizona. This reach of the San Pedro River system is referred to as the Upper San Pedro because the river flows from Mexico northward into the U.S. The San Pedro River is a free-flowing river and its associated desert riparian habitats lie between the Huachuca Mountains to the west and the Mule Mountains to the east.

The Upper San Pedro riparian system is composed of habitat types that include gallery forests dominated by Freemont cottonwood (*Populus fremontii*), Gooding willow (*Salix gooddingii*), and mesquite (*Prosopis* spp.) bosques with sacaton (*Sporobolus wrightii*) grass. Non-riparian habitat adjacent to the riparian system can be characterized as either desert scrub or agricultural land. In many areas along the river corridor distinct edges occur between the cottonwood forest, mesquite bosque, and desert scrub communities. The width of the NCA varies from 2 - 5 miles along the river corridor, and cattle grazing has been prohibited in this zone since the NCA was established in 1988.

By examining aerial photographs and ground-truthing, we selected four general study areas within the Conservation Area. Areas were selected to sample a habitat gradient perpendicular from the river corridor extending upslope into the desert scrub habitat. In the final selection of study sites, we chose locations composed of natural vegetation communities (non-agricultural lands), and sites that could accommodate sufficient survey points (approximately 14 points) to exhaust the morning sampling effort. It was not possible for us to randomly select sites within the NCA because we were limited by the number of locations that could accommodate 14 or more survey points. The four distinct study sites selected on the San Pedro River include: (1) Hereford, (2) San Pedro House, (3) Escapule Wash, and (4) Boquillas Ranch. At the southern and northern most sites, Hereford and Boquillas Ranch, respectively, we

placed sets of survey points in two separate locations. At Hereford, we placed points both north and south of the Hwy 10 bridge, and at Boquillas Ranch we placed points south and due west of the ranch.

Habitat Types

At each study location we classified the habitat into five types along the riparian to desert scrub gradient (based on a transect running perpendicular to the river channel). These include three core habitats -- primary riparian, secondary riparian, and desert scrub -- with an edge habitat type occurring between each transition of the core habitat. That is, edge habitats occurred in the transition from primary to secondary riparian habitat, and between secondary riparian and desert scrub. At many locations, primary riparian type could be further divided into two categories: (1) a floodplain area dominated by rabbit brush (*Chrysothamnus nauseousus*), seep willow (*Baccharis salicifolia*), and cockelbur (*Xanthium strumarium*), and (2) a gallery forest dominated by Freemont cottonwood and Gooding willow. Edge locations were generally very distinctive, both on the ground and in the aerial photographs (scale equal to 1:6500 ft. with sufficient resolution to locate individual cottonwood trees; these photographs, and remotely sensed TMS data are available for all sites, see cover of this report for an example).

Site Descriptions

Hereford: The Hereford sites are located 8 miles north of the United States / Mexico border. This area of the San Pedro River is dominated by cottonwood gallery forests surrounded by fallow and active agricultural fields and small remnant patches of sacaton grassland. At the Hereford North location, secondary riparian habitat is dominated by sacaton grass with a patchy distribution of individual mesquite trees. Desert scrub habitat was not present within the gradients sampled at this site. We placed four transect lines at Hereford North composed of 10 sample points. At Hereford South, riparian vegetation is dominated by cottonwood gallery forest, and old agricultural fields surround and abut the primary riparian habitat. Secondary riparian habitat is dominated by a mesquite bosque, and clumps of sacaton grass are interspersed within the mesquite bosque. We placed two transect lines, and established a total of 11 points at this location. Desert Scrub habitat was not present within the gradients sampled at this location.
San Pedro House: The San Pedro House site is located just south of Highway 90, approximately 15 miles north of the United States / Mexico border (see aerial photograph on cover of this report). The largest sacaton grassland on the Upper San Pedro occurs just north of Highway 90. This grassland and adjacent riparian habitat burned accidentally during late May, 1998. The habitat in this location is comprised of cottonwood gallery forest, mesquite bosque with sacaton grass, and desert scrub. We established 3 transect lines south of the Highway 90 bridge far enough from the highway so that traffic noise would not interfere with bird surveys. We positioned 11 sample points at this location.
Escapule Wash: Escapule Wash is located approximately 19.5 miles north of the United States / Mexico border. It is an intermittent arroyo that lies perpendicular to the San Pedro and channels water into the river from upland habitat in the Huachuca Mountains. Cottonwoods occupy a narrow band on either side of the Wash, and there is a well-developed gallery forest to the south of the wash at the river's edge. Beyond the narrow strip of cottonwoods there are mesquite bosques and desert scrub. In this location we had 2 transect lines with a total of 26 points.
Boquillas Ranch: The Boquillas Ranch site lies 25 miles north of the United States / Mexico border. In this area of the Upper San Pedro, mesquite bosques dominate the landscape and cottonwood gallery forests are less common. At this site we chose two locations at which to establish transect lines with survey points. The first location was south of the Boquillas Ranch

by approximately 1 mile. This study location occurs on a large meander in the river. We placed the transect lines in the open floodplain of the primary riparian zone, through a mesquite bosque, and extending into the upland desert scrub. We placed 3 transect lines with 17 points.

The second study location at the Boquillas Ranch was due west of the ranch house. This location is on a raised hydrologic bench that is approximately 3 meters above the channel of the river. There is a narrow stringer of cottonwood trees on the cliff edge of the raised bench, and a mesquite bosque dominates the landscape immediately west of the cottonwoods. The secondary to desert scrub edge habitat is less distinct at this location than at the other sites. The desert scrub covers an upsloping hill to the west of the river. We placed two transect lines at this location, with a total of 11 points.

Variable Circular Plots

At each location we established a set of permanent bird survey points – each point represents the center of a variable circular plot of 50-m radius. We positioned points along transect lines for the convenience of relocating the plot centers and for moving efficiently among them during bird survey periods. Each transect line was defined by a compass bearing that was perpendicular to the river at that location (see aerial photograph 5 for an illustrated example). Transect lines were at least 125 m apart so that no survey plots overlapped. We always positioned the first point on a transect line on the edge between primary and secondary riparian habitat types. After we established the first point on the edge between the primary and secondary riparian habitat types, we followed the compass bearing, and placed markers at 100-m intervals on either side of the first point. That is, we placed points in the primary riparian, secondary riparian, secondary riparian to desert scrub edge, and desert scrub zones. We did this until we had placed at least one, and sometimes two, points in the desert scrub habitat. Typically we did not allow transect lines to cross the river channel because high river flows brought on by monsoon rains can limit access to both sides of the river during early morning surveys.

We established permanent survey points by pounding an 18" piece of painted rebar into the ground and labeling each rebar piece with colored flagging. At each point we collected Universal Transverse Mercator (UTM) coordinates with a Garmin III Global Positioning System unit. To aid in estimating the distance of birds from point-center, we marked significant vegetation features with flagging tape, and measured the nearest-meter distance from the plot's center to the vegetation feature.

Survey Protocol

Two observers conducted 2 surveys at each of the 6 study locations from 29 July - 9 August, 1998. In total, 86 variable circular plots were sampled. At each point we recorded the number of individuals of each species, the estimated distance and direction of each individual bird from the observer (i.e., point-center), and how each detection was determined (sight, sound, or birds flying overhead and through the survey plot). We conducted surveys from 20 minutes before sunrise until three hours after sunrise. To allow birds to adjust to the presence of the observer, observers waited for one minute before beginning their five-minute sampling period. All detections of individuals were mapped on field sheets representing a specific circular plot marked with cross-hairs and with increments of 10-m.

Data Analysis

Species richness and community composition were determined in relation to five habitat types: primary riparian (PR), primary riparian to secondary riparian edge (EPS), secondary riparian (SR), secondary riparian to desert scrub edge (ESD), and desert scrub (DS). For the seven most common species, ($\geq$ 32 detections), density was determined in relation to the habitat types using

the program DISTANCE (Laake et al. 1994). The analysis was based on estimated distances of birds from the center of each point (n = 86) with points considered as replicates. The location data for each species were pooled across points within a habitat type. These data (distance to detection) were used to estimate a detection function for each species-habitat combination following the methods in Buckland et al. (1993). A detection function is needed to adjust the raw count of birds for those present, but undetected, within the 50-m radius circular plot.

For each species in each habitat type, four models were fit to the data: half-normal with hermite polynomials, uniform with simple polynomials, uniform with a cosine adjustment, and a hazard rate model with a cosine adjustment (see Buckland et al. 1993). In each case, the best model was chosen based on multiple likelihood ratio tests using Akaike information criterion (Buckland et al. 1993).

First-year Results and Conclusions

Forty-eight species were detected during the course of the study. The community composition and number of individuals of each species detected for each habitat type is shown in Table 1. Based on these preliminary data, species richness was highest in the secondary riparian habitat and lowest in the edge transition between secondary riparian and desert scrub habitat (Table 1).

Table 1. Number of individuals detected for each species in each type of habitat listed in order of decreasing number of total detections.

Species	PR	EPS	SR	ESD	DS	TOTAL
Bewick's Wren	28	15	16	15	7	**74**
Abert's Towhee	18	15	11	9	4	**57**
Yellow-breasted Chat	12	19	14	3	-	**48**
Lucy's Warbler	2	4	20	7	13	**46**
Yellow Warbler	19	10	5	4	-	**38**
House Finch	3	8	8	14	4	**37**
Black-throated Sparrow	-	-	2	8	22	**32**
White-winged Dove	18	9	1	2	1	**31**
Brown-headed Cowbird	7	7	10	3	3	**30**
Lesser Goldfinch	10	3	6	2	4	**25**
Blue Grosbeak	5	8	4	4	2	**23**
Common Yellowthroat	10	5	7	1	-	**23**
Cassin's Kingbird	10	4	1	-	6	**21**
Summer Tanager	9	3	5	-	-	**17**
Vermilion Flycatcher	10	1	4	-	-	**15**
Verdin	-	2	4	5	4	**15**
Gila Woodpecker	2	4	5	3	-	**14**
Bushtit	-	-	1	-	13	**14**
Black-chinned Hummingbird	2	2	8	-	1	**13**
Song Sparrow	8	3	-	-	-	**11**
Mourning Dove	5	1	1	2	1	**10**
Cassin's Sparrow	-	-	-	-	9	**9**
Common Ground-Dove	2	1	5	-	-	**8**
Northern Flicker	3	3	-	-	-	**6**
Bell's Vireo	1	2	2	1	-	**6**
Western Wood Pewee	2	2	-	2	-	**6**
Brown-crested Flycatcher	1	4	-	-	-	**5**
Ash-throated Flycatcher	-	-	4	-	1	**5**

Rock Wren	-	-	-	1	4	5
Northern Cardinal	-	-	4	-	-	4
Crissal Thrasher	-	1	2	1	-	4
White-breasted Nuthatch	4	-	-	-	-	4
Lazuli Bunting	-	-	-	-	4	4
Northern Rough-winged Swallow	-	-	-	-	4	4
Northern Mockingbird	-	-	1	-	2	3
Rufous-crowned Sparrow	-	-	2	-	1	3
Lesser Nighthawk	-	-	-	1	2	3
Great Blue Heron	2	1	-	-	-	3
Ladder-backed Woodpecker	-	-	1	-	2	3
Swainson's Hawk	2	-	-	-	-	2
Western Kingbird	1	-	-	-	1	2
Black Phoebe	1	1	-	-	-	2
Botteri's Sparrow	2	-	-	-	-	2
Canyon Towhee	-	-	-	1	1	2
Northern-bearded Tyrannulet	-	-	-	1	-	1
Gambel's Quail	-	-	1	-	-	1
Yellow-billed Cuckoo	-	-	-	1	-	1
Black-headed Grosbeak	-	-	1	-	-	1
TOTAL Number of Individuals	**116**	**139**	**83**	**199**	**156**	**693**
TOTAL Number of Species	**29**	**28**	**30**	**22**	**25**	**48**

Bird Density was estimated for the seven most common species. For the estimation of density, the Uniform/Cosine model was selected for the Bewick's Wren and Lucy's Warbler, the Uniform/Polynomial model for the Black-throated Sparrow, Yellow Warbler, Yellow-breasted Chat, and Abert's Towhee, and the Hazard/Cosine model for the House Finch. For the seven species estimates, total density (all habitats combined) was greatest for the Bewick's Wren at 1.25 birds per ha and least for the Black-throated Sparrow at 0.25 birds per ha. Bird density was also estimated for each species in each habitat type and was highest for the Bewick's Wren in the primary riparian habitat (Table 2).

Table 2. Density (mean ± standard error) and degrees of freedom for the most common species in relation to the type of habitat.

Species	PR		EPS		SR		ESD		DS	
	mean±se	df	mean±se	df	mean±se	df	mean±se	df	mean±se	df
BEWR	1.64±0.28	39	1.38±0.33	19	1.47±0.35	21	0.98±0.33	13	0.57±0.20	18
ABTO	0.68±0.18	38	0.88±0.27	32	0.65±0.23	20	0.79±0.30	16	0.16±0.11	20
YBCH	0.43±0.14	39	1.06±0.29	33	0.78±0.25	23	0.22±0.16	13	0	
LUWA	0.15±0.09	25	0.48±0.20	15	2.41±0.44	17	1.13±0.34	12	1.39±0.31	18
YWAR	1.19±0.24	36	0.85±0.26	19	0.42±0.19	16	0.11±0.11	11	0	
HOFI	0.23±0.10	32	0.96±0.28	19	0.96±0.28	18	2.24±0.49	14	0.43±0.17	19
BTSP	0		0		0.09±0.09	15	0.52±0.23	11	0.81±0.24	17

Common bird species show different patterns of density in relation to the type of habitat and type of edge. The Yellow Warbler had its highest density in primary riparian habitat and decreased in density along the habitat gradient from riparian to desert habitat (Table 2, Figure 1). Thus, these

preliminary data suggest that this species selects the riparian zone (primary and adjacent edge) with a steep reduction in density in the transition to secondary riparian habitat. The Bewick's Wren and Abert's Towhee showed a constant density across habitat types until desert scrub was encountered, suggesting a rather generalized pattern of selection for desert riparian habitats. In contrast, the Yellow-breasted Chat reached its highest density in the primary to secondary riparian edge (Table 2, Figure 1) suggesting an edge exploiter. Lucy's Warblers have the highest density in the secondary riparian habitat but extended their distribution into desert scrub habitat (Table 2, Figure 2). Finally, the Black-throated Sparrow appears to select for desert scrub, reaching its highest density in this habitat (Table 2, Figure 2).

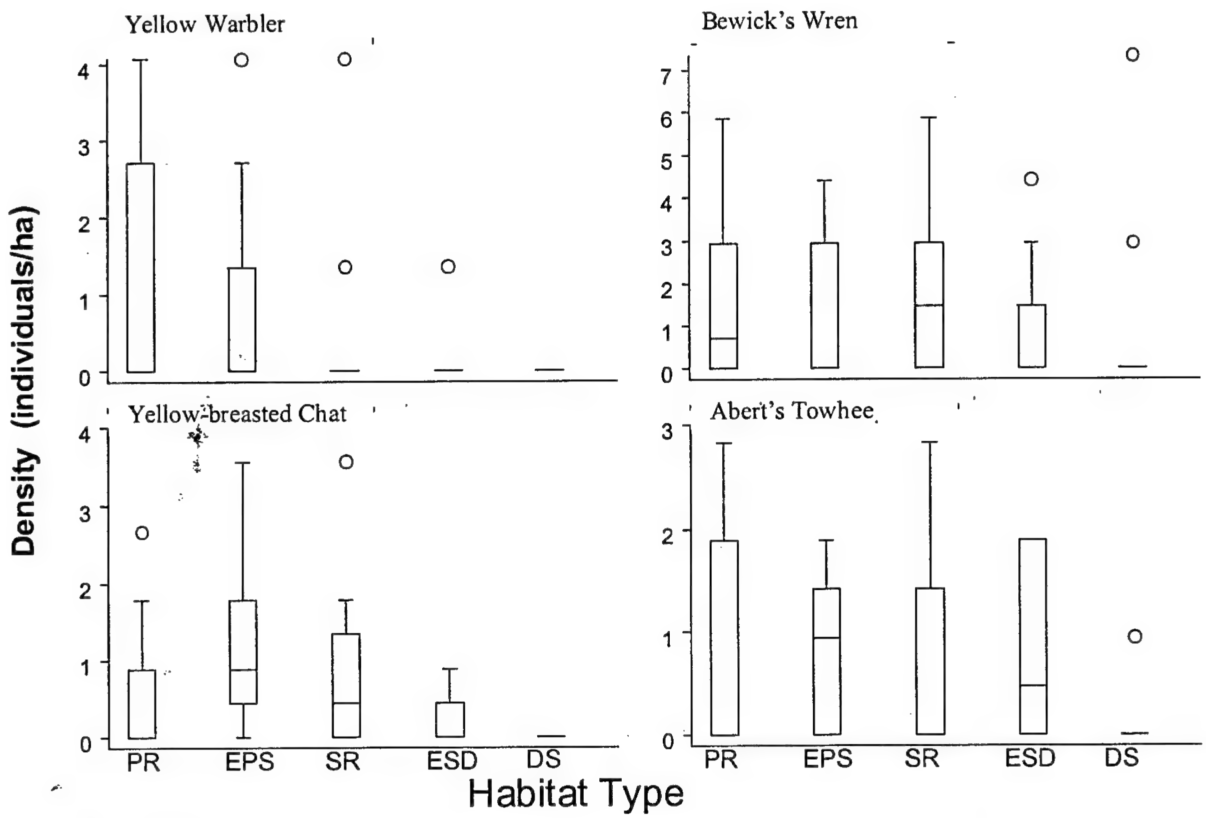


Figure 7. Box and whisker plots of the density of Yellow Warblers, Bewicks's Wrens, Yellow-breasted Chats and Abert's Towhees in relation to the five habitat types. The line in the middle of the box represents the median. The box extends from the 25th percentile to the 75th percentile. The farthest lines emerging from the box, or the points, show the minimum and maximum of the data.

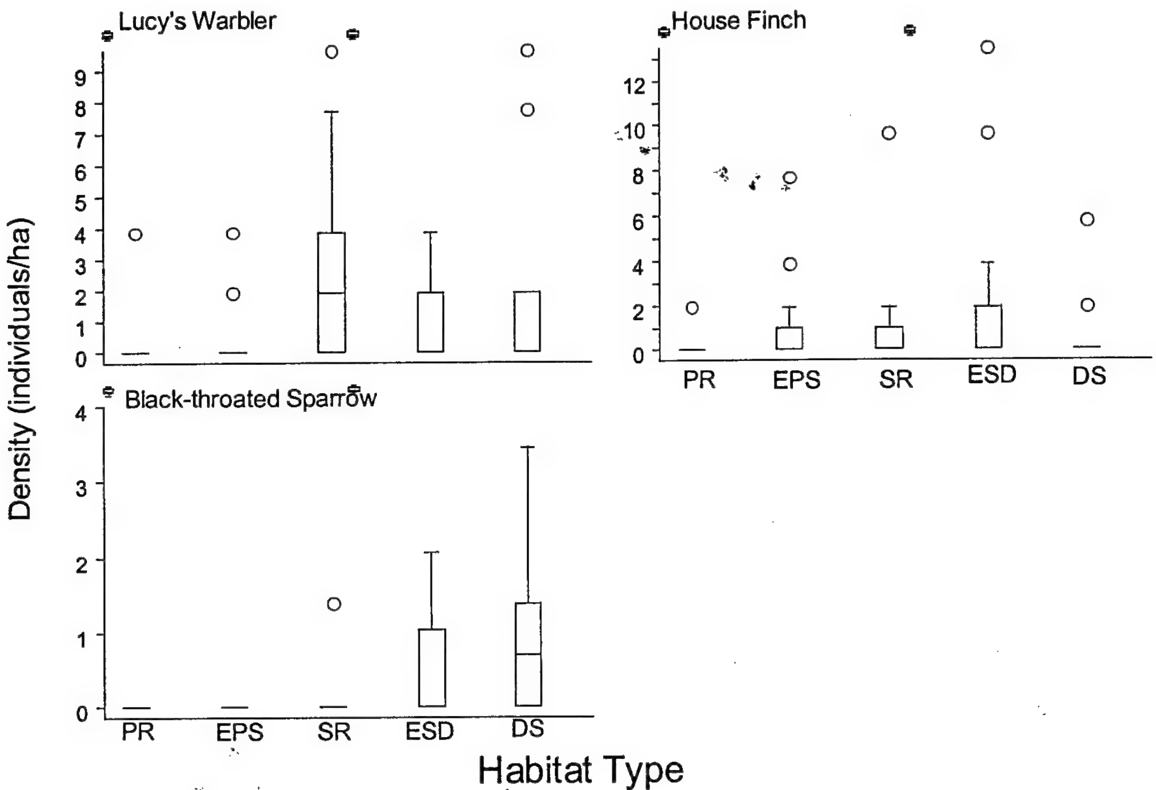


Figure 8. Box and whisker plots of the density of Lucy's Warblers, Black-throated Sparrows and House Finches in relation to the five habitat types. Symbols are as in Figure 1.

Part II: Preliminary Findings from Studies of Edge Responses of Birds in Ponderosa Pine Forests

Study Sites and Methods

Ponderosa pine restoration has begun on the Mount Trumbull area and is slated to begin at Camp Navajo in about one year. Our objectives for the first year of this part of the project were to: 1) test our methodology for determining edge responses, 2) make a preliminary assessment of avian edge responses at two types of edge, and 3) begin the collection of pre-treatment bird abundance data. In order to maximize the power of our analysis, we employed a before-after-control-impact-pairs (BACIP) design (Stewart-Oaten et al. 1986). This type of design allows us to control for both between-year and between-location differences in bird abundance. The BACIP design involves conducting surveys in control and treated areas before and after treatment.

Bird Survey Methodology

In order to assess the responses of individual bird species to natural and anthropogenic edges in ponderosa pine forests, we conducted bird surveys along transects that bisected both types of edge. Five natural edges were surveyed at Camp Navajo, and 8 edges between treated and untreated stands were studied at Mount Trumbull. The natural edges were transitions between ponderosa pine forest and naturally occurring meadows. In addition to these surveys, we established pre-treatment survey transects at both Camp Navajo and Mount Trumbull. At Camp Navajo, we established 4 such transects; at Mount Trumbull we established 8.

Transects consisted of five point-count stations spaced 100 m apart along a straight line oriented perpendicular to the edge. The midpoint of each transect was located on the edge, with

two points in each adjoining habitat, at 100 m and 200 m from the edge. At each point, three 5 minute, 50-m fixed-radius point counts were conducted during June and the first week of July, 1998. At Camp Navajo, the first round of counts was conducted from 3 - 5 June, the second round from 15 - 18 June, and the third round between 29 June to 3 July. At Mount Trumbull, the first round of counts was conducted on 3 June, the second round on 13 June, and the third round on 25 June.

First-year Results

In a total of 375 surveys at both study sites, we detected 890 individual birds of 48 species, representing 16 families (Appendix Ia, Ib). This works out to an average of 2.37 birds detected per survey. At Camp Navajo, we recorded 299 individuals of 33 species, while at Mount Trumbull we recorded 591 individuals of 39 species. The three most frequently observed species at Camp Navajo—Dark-eyed Junco, Mountain Chickadee, and Western Bluebird—accounted for 38% of all birds observed. At Mount Trumbull, the three most frequently detected birds—White-breasted Nuthatch, Western Tanager, and Dark-eyed Junco—accounted for 25% of all individuals.

To measure the response of birds to edges between restored and unrestored forests, we examined patterns of abundance for the nine most numerous bird species detected on our 8 edge survey transects at Mount Trumbull. Of these nine species, three (Mountain Chickadee, Yellow-rumped Warbler, and Western Tanager) showed no discernable response to edge or habitat type (Fig. 9a). One (Steller's Jay) was a possible edge-exploiter (Fig. 9b). The other five species were all more abundant in the restored forest than in the unrestored forest. Of these, two (White-breasted nuthatch and Solitary Vireo) showed an edge-avoiding response (Fig. 9c), while for the other three (Western Bluebird, Grace's Warbler, and Dark-eyed Junco) we detected no edge response.

In our study of bird responses to natural edges, only three species were observed frequently enough (n>20) to determine response patterns. Of these, two were most abundant in pine forest and one in meadow. Dark-eyed Junco was most abundant in pine forests and appeared to demonstrate a pattern of edge avoidance. Mountain Chickadee was also most abundant in pine forests but showed no edge avoidance. Western Bluebird was most abundant in meadows and appeared to avoid edge areas (Appendix I).

At least two classes of edge response were evident in the species we studied. We clearly saw both edge avoidance and edge neutrality in several species. Only one species—Steller's Jay—might have been an edge exploiter, but our sample size was too small to determine this with any certainty. Our study of bird responses to edges

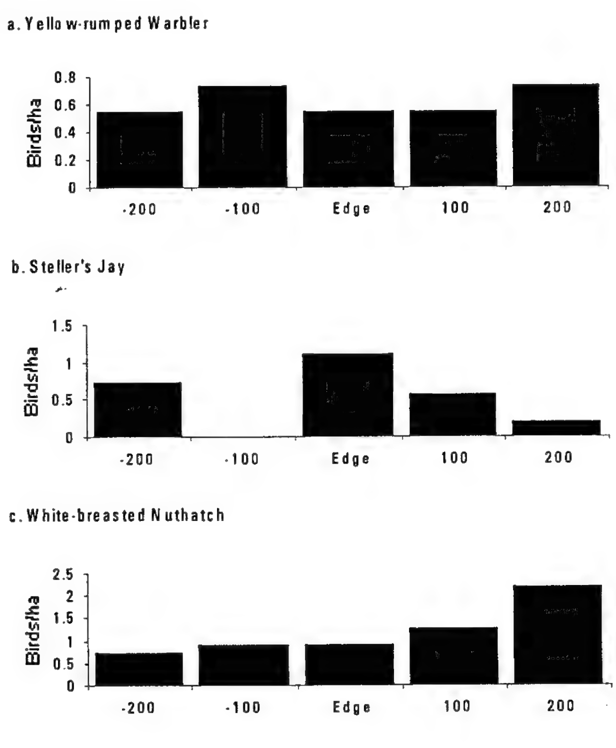


Figure 9. Relative abundances of: a) an edge-neutral species (Yellow-rumped Warbler, b) a possible edge-exploiter (Steller's Jay), and c) an edge-avoider that prefers restored forest (White-breasted Nuthatch).

between restored and unrestored ponderosa pine forests showed that no species for which we had a sufficient sample size was more abundant in unrestored than in restored forest. Several species were more abundant in restored forest.

Responses to natural and anthropogenic edges differed for the three species for which we could analyze both edge types (Mountain Chickadee, Western Bluebird, and Dark-eyed Junco). Both Western Bluebird and Dark-eyed Junco showed no edge response in restored-unrestored edges but a strong response in natural edges. Mountain Chickadee showed no edge response at either edge type. However, this species showed a strong change in abundance across the natural edge but not the restoration edge. The fact that edge response changes depending on edge type illustrates the necessity of measuring organisms' responses to all relevant edge types.

Preliminary Conclusions

Objective 1. To determine effectiveness of survey methodology. We conclude that our survey methodology is adequate to detect edge responses but that more transects are needed to allow us to sample sufficient numbers of replicates. With the mean number of birds detected per survey being only slightly over 2, a large number of sample points will be necessary to accumulate sufficient bird observations to accurately determine edge responses on a species-by-species basis. As a result, we will establish more survey transects across both natural and restoration-induced edges during spring of 1999.

Objective 2. To make a preliminary assessment of edge responses. Our preliminary assessments indicate differences in edge responses based on edge type. Because of this, we will continue to assess edge effects separately for different types of edges.

Objective 3. To begin pre-treatment bird surveys. A set of pre-treatment surveys was successfully completed during the summer of 1998. Because of the low number of birds recorded, we will need to establish more pre-treatment survey points during spring of 1999.

Part III: Preliminary Findings from Studies of Edge Responses of Butterflies in Desert Riparian Habitats

Study Sites and Methods

The riparian area of the San Pedro River offers an excellent opportunity to study edge effects along naturally occurring habitat edges. The riparian corridor has two distinct zones of vegetation between the river and the surrounding desert scrub community that dominates the area. The zone closest to the river is characterized by gallery forests dominated by Fremont cottonwood (*Populus freemontii*) and Gooding willow (*Salix goodingii*). Between the cottonwood/willow forests and the surrounding desert scrub, there is a zone of vegetation which consists either of Sacaton (*Sporobolus wrightii*) grassland or a heterogeneous landscape with a mix of grassland and mesquite (*Prosopis* spp.) as illustrated on the cover of this report. The changing nature of the landscape, due primarily to increased use of groundwater for agriculture and urban growth, may cause these vegetation zones to contract, creating a greater proportion of edge:interior ratio for all riparian habitats. Our goal for the 1998 summer season was to establish survey methods and document the edge responses of the most common butterflies in the San Pedro River Riparian Area.

Butterfly Survey Methodology

Three study areas were established along the San Pedro River corridor. Two study areas, San Pedro House (SPH) and Boquillas Ranch West (BRW), have secondary vegetation zones characterized by a mesquite/grassland mix (see Part I for detailed descriptions). The third area,

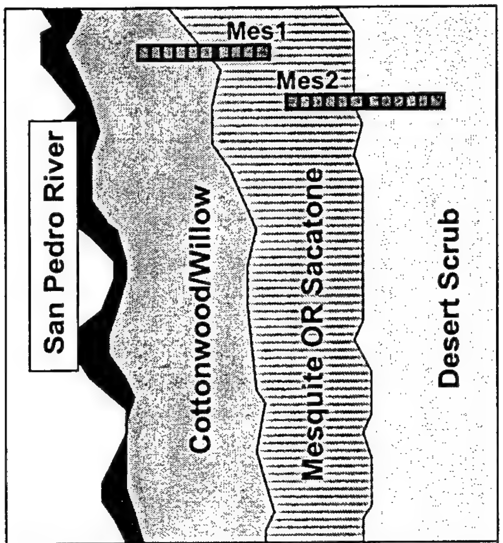


Figure 10. The main vegetation zones of the San Pedro River. Transects made up of 10 x 10 m quadrats spanned both edge types.

South San Pedro (SSP) was established two miles south of SPH and has a secondary vegetation zone dominated by sacaton grassland. Transects for butterfly surveys were established across three edge types: cottonwood/willow - mesquite (CW - Mes), mesquite - desert scrub (Mes - DS) and cottonwood/willow - sacaton (CW - Sac). Transects were composed of a contiguous line of 10 x 10 m quadrats that extended anywhere from 40 - 100 meters from the edge in both directions (Figure10).

In all, there were 228 10 x 10 m quadrats within the 16 transects. There were eight CW-Mes transects (four each at BRW and SPH), four Mes-DS transects (two each at BRW and SPH), and four CW - Sac transects at SSP. Due to the extensive variability within each habitat type, several habitat variables were recorded for each 10 x 10 meter survey quadrat, including canopy cover, percent cover and height of shrubs, and the abundance of grasses and forbs.

Butterfly surveys were conducted at each transect three times between 7 Sept 1998 and 3 Oct 1998. Surveys were conducted between 0800 and 1630 on sunny days with low wind. Surveys lasted three minutes and all individuals seen during the survey were recorded. Temperature, cloud cover, and wind speed were also recorded during each survey.

First-year Results

A total of 1,677 individuals of 43 species were recorded during 696 surveys. Most species were only recorded a few times throughout the summer, but seven species were abundant enough for a preliminary analysis of edge response. Appendix II includes a list of all 43 species and the average number of detections at each distance from the edge. Habitat preferences were varied, but all species showed a sharply lower abundance in the desert scrub. Although there was a great deal of variation in response, two edge response patterns did emerge. Five out of seven species (Orange Sulpher, *Colias eurytheme*;

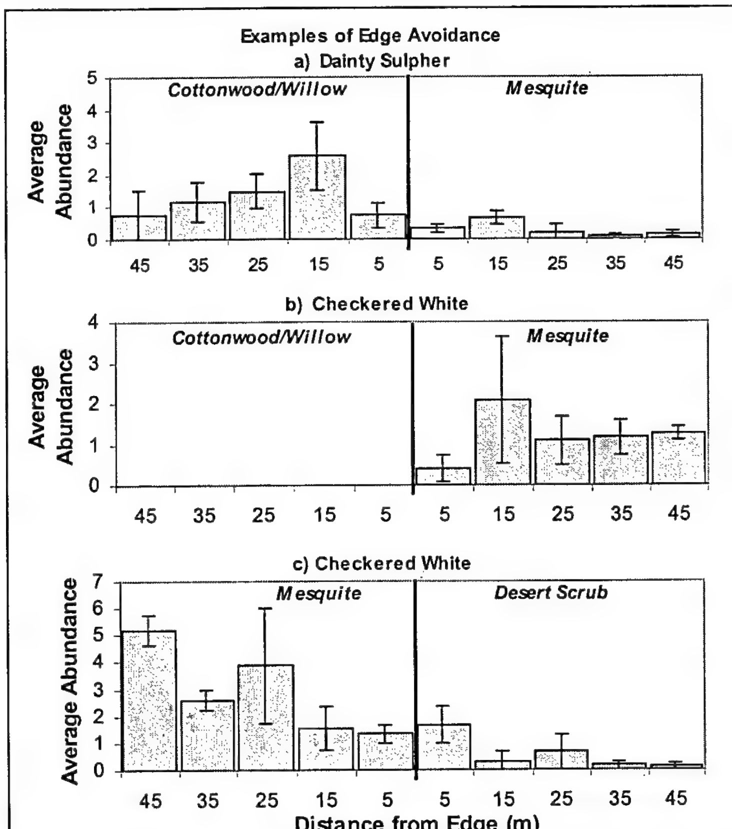


Figure 11. Examples of edge avoidance of the dainty sulpher (a) and the checkered white (b) at Cottonwood/Willow - Mesquite edges and the checkered white (c) at Mesquite - Desert Scrub edges.

Dainty Sulpher, *Nathalis iole*; Checkered White, *Pieris protodice*; Queen, *Danaus gilippus*; and Cloudless Sulpher, *Phoebis sennae*) showed a reduction in abundance near the edge (see Appendix II for details on all five species and Figure 11 for an illustration of the responses of two species). For all species, the edge response occurred within 10 to 20 meters from the edge. The remainder of the seven species (Pipevine, *Battus philenor* and Checkered Skipper, *Pyrgus communis*) examined showed no obvious edge response (both are illustrated in Figure 12). No species were shown to have their highest abundance at the edge. Species richness and the total number of individuals (all species included) were also reduced within 10 - 20 meters of the edge (Appendix II).

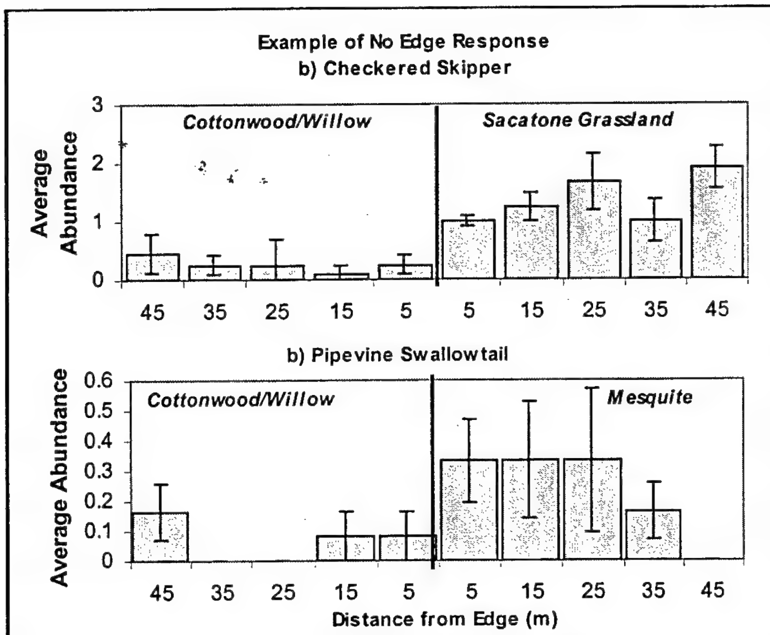


Figure 12. Examples of edge avoidance of the checkered skipper (a) at Cottonwood/Willow - Sacatone edges and the pipevine swallowtail (b) at Cottonwood/Willow - Mesquite edges.

Preliminary Conclusions

We detected an edge effect for over half of the most common species in the San Pedro River riparian area. In all cases, individuals showed a response within 10 - 20 meters of the edge (Figs. 11 and 13). This range of response is consistent with other studies tracking butterfly responses near edges (Haddad 1997, Ries 1998). Although several species were not abundant enough to perform individual analyses, the fact that overall abundance and richness were reduced near the edges (Appendix II) indicates that this pattern may be evident among several species. This reduction of species richness near edges differs from many edge studies, which commonly show an increase in richness and abundance near edges (Yahner 1998).

Although several species showed a strong edge response, there was a great deal of variability in response. This is most likely due to the heterogeneous nature of the riparian habitat along the San Pedro River. Both the cottonwood/willow and mesquite zones showed a great deal of variation in the degree of several habitat factors, including canopy cover, ground cover, and nectar availability. These factors have been shown to have a strong influence on the distribution of butterflies. Preliminary analysis, however, indicates that the edge response we found is not strongly tied to any one habitat variable.

The results of our first season of data collection indicate that there is a measurable edge response in butterfly species in the San Pedro River riparian habitat. Preliminary analysis indicates that our survey methods were adequate to document patterns of butterfly abundance. However, the degree of habitat variability indicates a need to more rigorously take habitat variability into account in our future sampling efforts. During our next field season, we will stratify our study design to account for the structural variability within the two riparian habitat zones. This will allow us to more rigorously document edge responses and allow us to determine the mechanisms which underlie these responses.

Part IV: Preliminary Findings from Studies of Butterfly Distribution Across Edge Gradients in Ponderosa Pine Forests

Study Sites and Methods

Large-scale restoration treatments of ponderosa pine forests in northern Arizona are creating a unique opportunity to study butterfly response to habitat heterogeneity and edges. The current forest structure has changed markedly from the historic ponderosa pine structure, and a major effort to restore the forest to more open, park-like stands resembling historic conditions has been undertaken at several locations in northern Arizona. This large landscape-scale experiment offers an opportunity to examine butterfly responses to changes in management that affect forest structure and understory vegetation distribution. The main emphasis of field work over the past summer was to collect butterfly distribution data and determine responses of multiple species to edges in ponderosa pine forest.

We currently are working at two ponderosa pine study sites. Camp Navajo Army Depot, located 10 miles west of Flagstaff, is characterized by ponderosa pine forest interspersed with natural meadows. Restoration treatments have not begun at this site, but are planned for 1999. At Mt. Trumbull on the north rim of the Grand Canyon, restoration treatment has already begun, with more slated to begin in the near future.

Butterfly Survey Methodology

At Mt. Trumbull, we established sixteen 400-m butterfly sampling transects. Eight transects cross edges between restored and unrestored ponderosa pine forest, while the remaining eight transects cross prerestoration forest and will be bisected by restoration treatments planned for 1999. At Camp Navajo, five 400-m butterfly transects cross edges between control ponderosa pine forest and natural meadows, and five transects in prerestoration sites will be bisected by the restoration treatment (Figure 13). Here we report butterfly response for transects crossing existing edges at both sites. Data from all transects is presented in Appendix III.

We employed a transect count method at both sites, walking at a pace of 100 m per 5 min. When a butterfly was seen, the transect timer was paused, and the point along the transect, the lateral distance from the transect, and the species of the butterfly (when possible) were recorded. The Mt. Trumbull transects were surveyed three times and the Camp Navajo transects were surveyed five times over the course of the summer. In order to examine the edge response of particular species, count data were divided into five categories representing edge, 100 m, and 200 m from the edge into each habitat type (Figure 13).

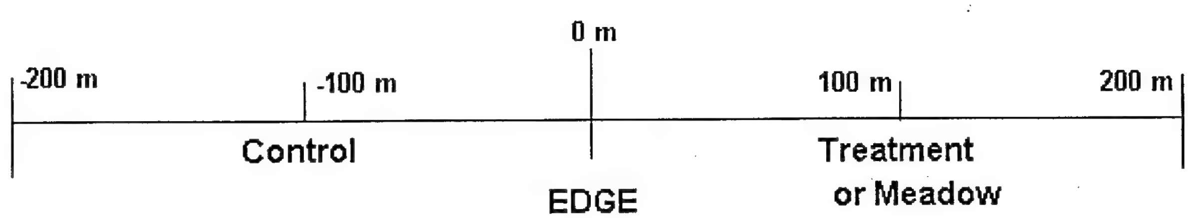


Figure 13. Diagram of butterfly sampling transects; the control represents unrestored ponderosa pine forest and the treatment represents restored forest or natural meadow.

First-year Results

Throughout the summer butterfly transects were surveyed at both the Mt. Trumbull and Camp Navajo sites. Over 30 species were identified during surveys at both sites, and some of these species appear to exhibit an edge response. The butterfly species presented below were chosen based on sample size and their response to the edge. For example, the Variegated Frittilary (*Euptoieta claudia*) is a species that appears to avoid the edge (Figure 14). This butterfly was detected predominately in the natural meadow at Camp Navajo and rarely in the dense control ponderosa pine forest. The Orange Sulphur (*Colias eurytheme*) is a species that does not exhibit an edge response. This response was true at both sites for the Orange Sulphur. The Sulphur clearly prefers the open meadow or restored areas to the dense control forest, but is not affected by the presence of the edge (Figure 14). For most species, there were not sufficient detections to clearly characterize edge responses (See Appendix III).

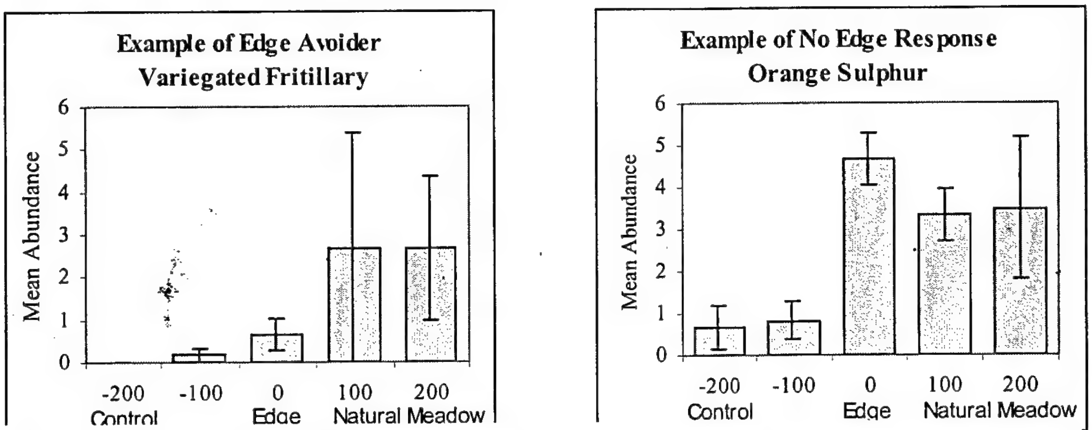


Figure 14. Edge responses for two butterfly species edges between unrestored ponderosa pine forest and open forest/meadow habitats at the Camp Navajo study site.

Preliminary Conclusions

Most of the butterfly species surveyed at ponderosa pine edges exhibited sensitivity to habitat type and forest structure. Fewer exhibited obvious changes in abundance near habitat edges. This may be due to low sample size and more sampling effort may be needed to detect a response. One reason for this may be the high degree of variation due to natural habitat heterogeneity within the ponderosa pine forest type. Even at the prerestoration sites the forest was patchy, with small openings relatively common throughout. Butterflies may be keying on these openings within the forest and not responding as strongly to the landscape-scale edge present at the boundary between natural meadow and ponderosa pine or restored and denser ponderosa pine forest. Efforts to characterize the influence of internal heterogeneity on butterfly abundance are underway (Kelly, in prep.) and will be expanded during 1999.

These preliminary analyses indicates that our survey methods are adequate for documenting patterns of butterfly abundance across a heterogeneous landscape. The degree of patchiness inherent in this forest type dictates a need for applying these methods in a stratified sampling design, with greater replication of transects.

Part V: Preliminary Findings from Studies of Microclimatic Gradients Across Edges Associated with Ponderosa Pine Restoration

Study Sites and Methods

In order to understand edges on a landscape scale, we are addressing mechanistic factors that underlie edge effects. Among the most important physical variables influencing nesting birds and adult butterflies are microclimatic factors. Characterizing microclimate across heterogeneous landscapes will allow us to gain insight into the abiotic factors that underlie patterns associated with habitat edges. Large scale restoration treatments of ponderosa pine forests in northern Arizona are resulting in markedly different forest structure. This landscape-scale experiment enables us to examine the interaction of microclimates with plant and animal distribution in a controlled, replicated design. During this first field season, our objectives were to develop methods for quantifying microclimatic variation across this heterogeneous landscape, and to determine whether dramatic shifts in microclimate are associated with habitat edges. We worked at both the Camp Navajo and Mt. Trumbull study sites (see descriptions of study sites and transects, above).

We also collected preliminary microclimatic data from riparian habitats in along the San Pedro River in southeastern Arizona. Analysis of these data have begun only recently, and results are not presented in this report.

Measuring the Microclimatic Gradient

Light intensity, air temperature, and relative humidity were collected at 1 m above the ground at nine points along each transect at 100m, 50m, 25m, 10m, and 0m from the edge, extending into both habitat types (Figure 15). Data were collected at five-minute intervals for one 24 hour period along each transect, during clear skies, at all points along each of the transects. Results presented below are derived from daylight hours, from 0600 to 1800.

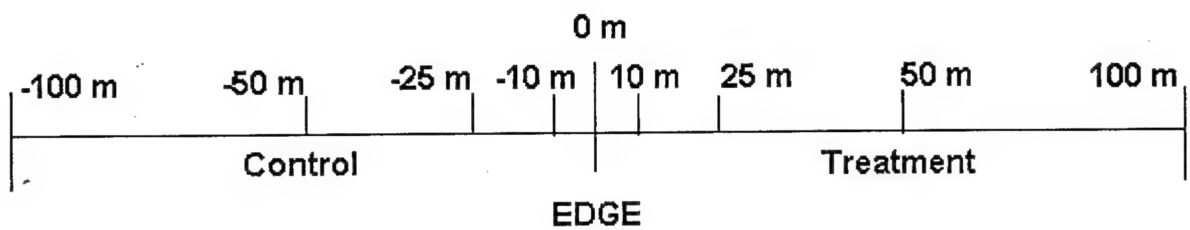


Figure 15. Diagram of transects; the control portion of the transect represents dense, unrestored ponderosa pine forest; the treatment portion represents restored ponderosa pine forest or open habitat.

First-year Results

Mount Trumbull: Interior, dense, present-day forests (control) had significantly lower light intensity and air temperature ($p<0.02$) and significantly higher relative humidity ($p<0.02$) compared to both the edge and the restored forest (treatment) areas. Treatment areas did not differ significantly from the edge with respect to any of the variables (Figure 16). The changes observed in microclimate were generally intermediate across the edge. Both light intensity and air temperature exhibited high variability near the edge, but a positive trend is apparent from the control, across the edge, and into the treatment. Relative humidity exhibited the reverse trend, with percent humidity decreasing from the control across the edge into the treatment (Figure 17).

Camp Navajo: The Camp Navajo transects used for these results were affected by rain from heavy monsoonal weather patterns that developed in northern Arizona during mid-summer, 1998. Cloudy days mute the differences in microclimatic variables among structurally distinct habitats. Nevertheless, the microclimatic gradients measured on cloudy days resemble the edge gradients measured at Mt. Trumbull. Light intensity exhibited high variability near the edge, but a positive trend is apparent from the control across the edge into the meadow (Figure 18). Both air temperature and relative humidity exhibited the same general trend at Mt. Trumbull (comparing Figures 17 and 18). Air temperature shows a positive trend across the edge and relative humidity shows the reverse of this trend by decreasing across the edge into the natural meadow. Error bars indicate the high degree of variability due to the changing weather pattern on the days the data were collected.

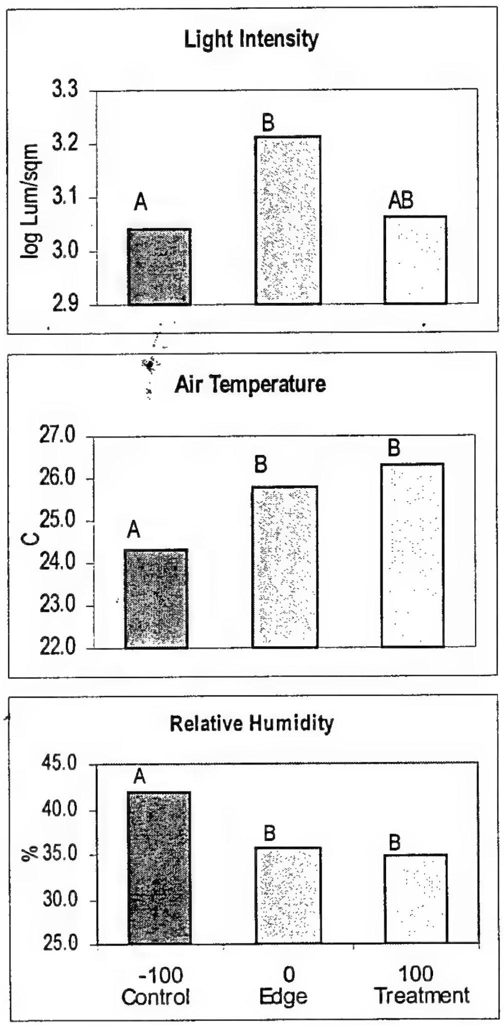


Figure 16. Comparison of microclimatic variables at Mt. Trumbull for interior ponderosa pine forest (control), edge, and interior restored ponderosa pine forest (treatment). Letters distinguish habitat types that differ significantly.

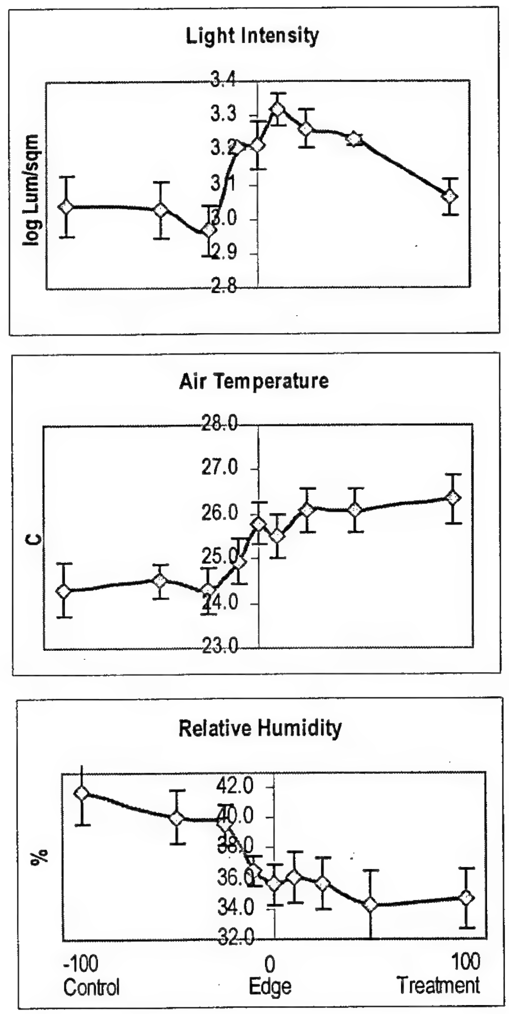


Figure 17. The average of six transects across edge gradients created by restoration treatments at Mt. Trumbull during clear summer days.

Preliminary Conclusions

Preliminary results indicate the presence of a distinct microclimate gradient that changes abruptly across ponderosa pine edges. During daylight hours, light intensity and air temperature are generally higher in the open areas and decrease across the edge into the control, dense ponderosa pine forest. Relative humidity exhibits the opposite trend, registering lower values in the open areas and increasing across the edge. These overall trends are not unexpected.

The great variation apparent in the microclimatic gradients as they cross habitat edges, however, is less intuitive. What factors cause light intensity to drop immediately at the edge (Figure 18) and what factors are causing the dips present in air temperature and relative humidity as we approach the edge (Figures 17 and 18)? Are these observed gradients biologically significant? Addressing these questions and determining the steps for the next field season are the present focus of this study. Also, stratification of sampling techniques is being explored to see if this will provide a means for reducing variance in microclimate characterization of inherently patchy habitats.

Ultimately, we will attempt to correlate breeding bird densities and butterfly distributions, as well as hostplant and nectar resources, to microclimate gradients recorded across the study sites. Quantifying microclimatic shifts across habitat edges may prove to be a key component for mapping habitat quality and developing models that predict the effects of landscape fragmentation on the distribution and abundance of mobile animals.

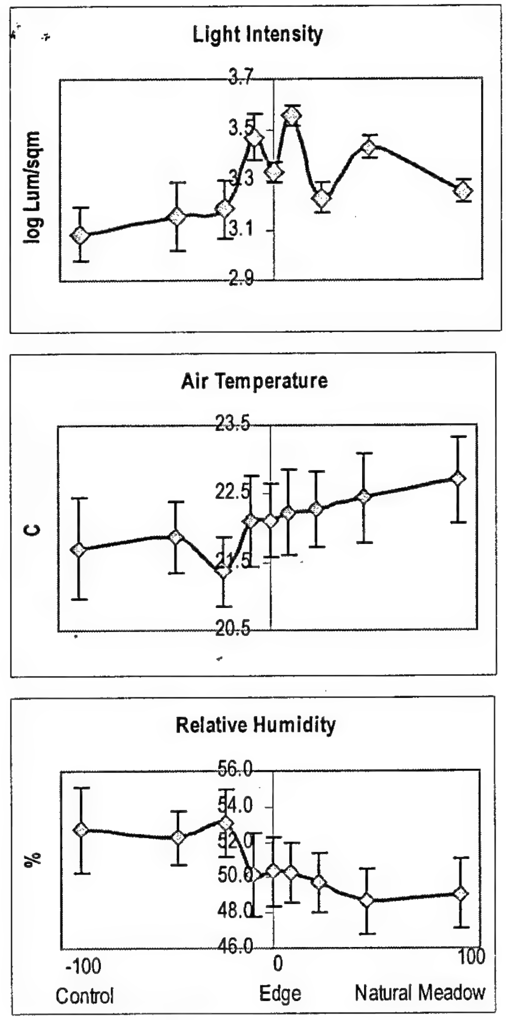


Figure 18. The average of four transects across edge gradients at Camp Navajo during clear summer days.

FUTURE RESEARCH PLANS

Analysis of preliminary data will continue over the coming months, with particular focus on power analysis and the identification of appropriate sampling efforts, based on variance seen in the preliminary data sets.

During spring/summer 1999 we will establish additional sampling locations at current study sites in both habitat types, and we will identify additional sites to be used in both model building and testing phases. Research on bird and butterfly assemblages and microclimatic gradients at ponderosa pine and riparian sites will be the dominant field activity in FY 99. Modeling efforts will focus on mathematical characterization of species responses and gradient analysis. We will initiate efforts to link specific edge responses to life history characteristics, such as foraging guild, nesting requirements, and physiological characteristics, as well as habitat

preference and specificity, which are expected to co-vary with some of the above. Hiring of a post-doctoral scholar or spatial analyst/modeling research technician will complete our research team. Two objectives of the GIS-modeling effort will be to link remotely-sensed imagery to field data, and to analyze landscape patterns and link these to edge response curves. This will allow us to generate predictions of impacts of landscape pattern on abundance patterns for multiple species. Sensitivity of the model to the amount of edge in focal landscapes will provide an early test of model utility. Additional details regarding these activities is available in the FY 1999 Execution Plan for SERDP project CS-1100.

LITERATURE CITED

Babbitt, B. 1997. A Coordinated Campaign: Fight Fire With Fire. Remarks of U.S. Secretary of the Interior. Boise State University, Idaho, February 11, 1997.

Buckland, S.T., D.R. Anderson, K.P. Burnham, and J.L. Laake. 1993. Distance Sampling. Chapman & Hall, London, U.K.

Covington, W.W., P.Z. Fulé, M.M. Moore, S.C, Hart, T.E. Kolb, J.N. Mast, S.S. Sackett, and M.R. Wagner. 1997. Restoring ecosystem health in ponderosa pine forests of the Southwest. Journal of Forestry 95:23-29.

Dunning, J.B., D.J. Stewart, B.J. Danielson, B.R. Noon, T.L. Root, R.H. Lamberson, and E.E. Stevens. 1995. Spatially explicit population models: Current forms and future uses. Ecological Applications, 5:3-11.

Fulé, P.Z., M.M. Moore, and W.W. Covington. 1995. Changes in ponderosa pine-Gambel oak forest structure following fire regime disruption in northern Arizona: Camp Navajo old-growth forest study. Final report to Arizona Army National Guard. 52 pp.

Hampton, H.M. Use of multichannel synthetic aperture radar to predict forest structure for bird habitat mapping. Masters thesis, Northern Arizona University, Flagstaff, AZ, *in preparation*.

Haddad, N.M. Using empirical estimates of local behaviors to model landscape-level movements of butterflies. Ecological Applications, *in press*.

Imhoff, M.L, T.D. Sisk, A. Milne, G. Morgan, and A. Orr. 1997. Remotely sensed indicators of habitat heterogeneity: Use of synthetic aperture radar in mapping vegetation structure and bird habitat. *In Press,* Remote Sensing of the Environment.

Laurance, W. F. and E. Yensen. 1991. Predicting the impacts of edge effects in fragmented habitats. Biological Conservation 55:77-92.

Laake, J.L., S.T. Buckland, D.R. Anderson, and K.P. Burnham. 1993. DISTANCE user's guide. Colorado Cooperative Fish and Wildlife Research Unit, Colorado State University, Fort Collins, CO 80523, USA.

Lynch J.F. and D.F. Whigham. 1984. Effects of forest fragmentation on breeding bird communities in Maryland, USA. Biological Conservation 28:287-324

Malcolm, J.R. 1994. Edge effects in central Amazonian forest fragments. Ecology 75:2438-2445.

Noon, B.R, and K.S. McKelvey. 1996. Management of the spotted owl: A case history in conservation biology. Annual Review of Ecology and Systematics 27:135-162.

Noss, R.F. 1991. Effects of edge and internal patchiness on avian habitat use in an old-growth hammock. Natural Areas Journal 11:34-47.

Pulliam, H.R., J.B. Dunning, and J. Liu. 1992. Population dynamics in complex landscapes: a case study. Ecological Applications 2:165-77.

Ranney, J.W., M.C. Bruner, and J.B. Levinson. 1981. The importance of edge in the structure and dynamics of forest islands. In: Burgess R.L., Sharpe D.M. (eds) Forest dynamics in man-dominated landscapes. Springer-Verlag, New York, pp 67-96

Reichman, O.J. and H.R. Pulliam. 1996. The scientific basis for ecosystem management. Ecological Applications 6:694-695.

Ries, L.R. Butterfly movements near prairie edges: the determinants of behavioral responses. *Submitted to Ecology.*

Robinson, S. K., F. R. Thompson III, T. M. Donovan, D. R. Whitehead, and J. Faaborg. 1995. Regional forest fragmentation and the nesting success of migratory birds. Science 267:1987-1990.

Samson, F.B. and F.L. Knopf. 1994. Scale perspective on avian diversity in western riparian ecosystems. Conservation Biology 8:669-676.

Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. Conservation Biology 5:18-32.

Sisk, T.D. 1992. Distributions of birds and butterflies in heterogeneous landscapes. Ph.D. dissertation. Stanford University, Stanford, CA.

Sisk, T.D. and C.R. Margules. 1993. Habitat edges and restoration: methods for quantifying edge effects and predicting the results of restoration efforts. Pages 57-69 in D.A. Saunders, R.J. Hobbs, and P.R. Ehrlich, editors. Nature conservation 3: reconstruction of fragmented ecosystems. Surrey Beatty & Sons, Sydney, Australia.

Sisk, T.D., N. Haddad, and P.R. Ehrlich. 1997. Bird assemblages in patchy woodlands: modeling the effects of edge and matrix habitats. *In press,* Ecological Applications.

Sisk, T.D. and J.R. Zook. Modeling effects of habitat edges on tropical animal distributions: Empirical tests and management applications. *In preparation.*

Stewart-Oaten, A., J. R. Bence, and C. W. Osenberg. 1992. Assessing effects of unreplicated perturbations. Ecology 73:1396-1404.

Szaro, R.C. and M.D. Jakle. 1985. Avian use of a desert riparian island and its adjacent scrub habitat. Condor 87:511-519.

Temple, S.A. 1986. Predicting impacts of habitat fragmentation of forest birds: a comparison of two models. Pp. 301-304 in J. Verner, M.L. Morrison, and C.J. Ralph editors. Wildlife 2000: modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

Temple, S.A. and J. R. Cary. 1988. Modeling dynamics of habitat-interior bird populations in fragmented landscapes. Conservation Biology 2:340-347

USFWS [U.S. Fish and Wildlife Service]. 1981. Standards for the development of suitability index models. Ecological Services Manual 103. U.S. Fish and Wildlife Service, Washington, D.C.

Whitcomb R.F., C.S. Robbins, J.F. Lynch, B.L. Whitcomb, M.K. Klimkiewicz, and D. Bystrak. 1981. Effects of forest fragmentation on avifauna of the eastern deciduous forest. In: Burgess R.L., and B.M. Sharpe (eds) Forest island dynamics in man-dominated landscapes. Springer-Verlag, New York, pp 125-206

Wiens, J.A. 1995. Habitat fragmentation: island v landscape perspective on bird conservation. Ibis 137:S97-S104.

Wilcox, B. A. and D. D. Murphy. 1985. Conservation strategy: the effects of fragmentation on extinction. American Naturalist 125:879-887.

Yahner, R.H. 1998. Changes in wildlife communities near edges. Conservation Biology 2:333-339.

LIST OF APPENDICES

Appendix Ia. Total numbers of birds detected at Camp Navajo for transects crossing pre-treatment (P) and natural edges (N).

		Number of Detections							
		Forest			Edge	Treatment			Grand
Treatment	Species	-200	-100	Subtotal	0	100	200	Subtotal	Total
P	Acorn Woodpecker	0	1	1	1	0	0	0	2
P	American Robin	3	0	3	1	0	1	1	5
P	Brown-headed Cowbird	0	0	0	1	2	1	3	4
P	Black-headed Grosbeak	0	1	1	1	0	1	1	3
P	Brown Creeper	0	4	4	1	3	3	6	11
P	Cordilleran Flycatcher	0	0	0	1	0	1	1	2
P	Dark-eyed Junco	3	2	5	4	5	5	10	19
P	Grace's Warbler	0	0	0	3	0	1	1	4
P	Lark Sparrow	1	0	1	0	0	0	0	1
P	Mountain Chickadee	1	2	3	2	1	6	7	12
P	Northern Flicker	0	0	0	1	0	0	0	1
P	Pygmy Nuthatch	2	3	5	2	0	0	0	7
P	Solitary Vireo	1	0	1	1	0	2	2	4
P	Steller's Jay	1	0	1	1	2	2	4	6
P	Townsend's Solitaire	0	0	0	0	0	1	1	1
P	Violet-green Swallow	0	0	0	1	0	0	0	1
P	Virginia's Warbler	1	1	2	2	1	6	7	11
P	White-breasted Nuthatch	3	1	4	1	2	2	4	9
P	Western Bluebird	0	2	2	2	3	9	12	16
P	Western Tanager	0	0	0	0	2	3	5	5
P	Western Wood-pewee	0	2	2	2	3	4	7	11
P	Yellow-rumped Warbler	0	1	1	0	1	1	2	3
N	American Crow	0	1	1	0	0	0	0	1
N	American Robin	2	1	3	1	2	0	2	6
N	Brown-headed Cowbird	1	0	1	1	0	0	0	2
N	Black-headed Grosbeak	1	0	1	0	0	0	0	1
N	Brown Creeper	0	0	0	2	0	0	0	2
N	Chipping Sparrow	0	0	0	0	0	1	1	1
N	Cordilleran Flycatcher	0	0	0	0	0	1	1	1
N	Cooper's Hawk	0	0	0	1	0	0	0	1
N	Dark-eyed Junco	5	7	12	3	2	4	6	21
N	Grace's Warbler	0	1	1	2	0	1	1	4
N	Hairy Woodpecker	0	0	0	1	0	0	0	1
N	Killdeer	0	0	0	0	0	1	1	1
N	Lark Sparrow	0	0	0	0	2	3	5	5
N	Eastern Meadowlark	0	0	0	1	0	0	0	1
N	Mountain Bluebird	0	0	0	0	0	5	5	5
N	Mountain Chickadee	6	10	16	7	4	1	5	28
N	Northern Flicker	2	1	3	1	0	2	2	6
N	Olive-sided Flycatcher	1	0	1	0	0	1	1	2
N	Pygmy Nuthatch	0	1	1	0	0	0	0	1

N	Red Crossbill	0	0	0	0	0	2	2	2	
N	Red-tailed Hawk	0	0	0	1	0	0	0	1	
N	Solitary Vireo	1	3	4	0	2	1	3	7	
N	Steller's Jay	2	3	5	0	0	1	1	6	
N	Vesper Sparrow	0	0	0	0	1	1	2	2	
N	Violet-green Swallow	2	0	2	3	0	2	2	7	
N	Virginia's Warbler	2	0	2	0	0	0	0	2	
N	White-breasted Nuthatch	1	1	2	1	1	2	3	6	
N	Western Bluebird	2	2	4	1	1	6	7	12	
N	Western Wood-pewee	0	0	0	1	2	0	2	3	
N	Yellow-rumped Warbler	0	0	0	1	0	0	0	1	

Appendix Ib. Total numbers of birds detected at Mount Trumbull for transects crossing pre-treatment (P) and restored edges (R).									
					Number of Detections				
			Forest		Edge		Treatment		Grand
Treatment	Species	-200	-100	Subtotal	0	100	200	Subtotal	Total
P	Acorn Woodpecker	0	0	0	4	2	1	3	7
P	American Robin	1	1	2	0	0	0	0	2
P	Black-chinned Hummingbird	0	0	0	0	1	0	1	1
P	Blue-gray Gnatcatcher	0	0	0	0	0	1	1	1
P	Black-headed Grosbeak	0	0	0	0	1	0	1	1
P	Brown Creeper	0	0	0	1	0	1	1	2
P	Black-throated Gray Warbler	3	5	8	0	0	0	0	8
P	Broad-tailed Hummingbird	0	1	1	1	1	0	1	3
P	Band-tailed Pigeon	0	1	1	0	2	0	2	3
P	Cassin's Finch	0	0	0	0	0	1	1	1
P	Chipping Sparrow	1	1	2	2	1	0	1	5
P	Clark's Nutcracker	2	0	2	0	0	0	0	2
P	Dark-eyed Junco	3	1	4	5	5	4	9	18
P	Dusky Flycatcher	1	2	3	0	0	1	1	4
P	Grace's Warbler	3	1	4	6	2	4	6	16
P	Hairy Woodpecker	4	0	4	0	1	2	3	7
P	Hermit Thrush	0	2	2	4	2	0	2	8
P	Mountain Chickadee	7	3	10	6	7	0	7	23
P	Northern Flicker	1	1	2	0	3	0	3	5
P	Pine Siskin	0	0	0	0	0	5	5	5
P	Pygmy Nuthatch	0	2	2	0	0	0	0	2
P	Red-breasted Nuthatch	2	0	2	1	0	2	2	5
P	Red Crossbill	1	4	5	3	0	7	7	15
P	Solitary Vireo	1	0	1	2	1	3	4	7
P	Spotted Towhee	3	3	6	2	1	4	5	13
P	Steller's Jay	1	5	6	3	1	5	6	15
P	Townsend's Solitaire	2	0	2	0	1	0	1	3
P	Virginia's Warbler	0	1	1	0	0	0	0	1
P	Warbling Vireo	0	1	1	0	0	0	0	1
P	White-breasted Nuthatch	4	3	7	7	8	6	14	28
P	Western Bluebird	0	3	3	1	1	2	3	7
P	Western Tanager	3	8	11	0	3	5	8	19
P	Yellow-rumped Warbler	3	2	5	5	3	2	5	15
R	Acorn Woodpecker	2	3	5	1	4	8	12	18
R	American Robin	0	0	0	1	3	0	3	4
R	Brown-headed Cowbird	0	0	0	1	0	0	0	1
R	Black-headed Grosbeak	0	1	1	2	3	3	6	9
R	Brown Creeper	0	0	0	1	1	0	1	2
R	Broad-tailed Hummingbird	1	0	1	0	0	0	0	1
R	Band-tailed Pigeon	1	1	2	0	0	0	0	2
R	Cassin's Finch	0	0	0	0	0	1	1	1
R	Chipping Sparrow	4	3	7	0	5	8	13	20

R	Dark-eyed Junco	4	1	5	6	6	5	11	22
R	Dusky Flycatcher	0	0	0	1	0	2	2	3
R	Grace's Warbler	3	1	4	5	4	6	10	19
R	Hairy Woodpecker	3	3	6	5	5	6	11	22
R	Hermit Thrush	2	0	2	0	0	0	0	2
R	Lark Sparrow	0	0	0	0	1	0	1	1
R	Mountain Chickadee	2	5	7	3	3	2	5	15
R	Mourning Dove	0	1	1	2	0	3	3	6
R	Northern Flicker	0	0	0	1	4	1	5	6
R	Olive-sided Flycatcher	0	0	0	0	0	1	1	1
R	Pygmy Nuthatch	0	0	0	2	1	1	2	4
R	Red-breasted Nuthatch	1	1	2	0	2	11	13	15
R	Red Crossbill	4	4	8	3	6	10	16	27
R	Spotted Towhee	5	3	8	0	1	4	5	13
R	Steller's Jay	4	0	4	6	3	0	3	13
R	Townsend's Solitaire	0	3	3	1	0	0	0	4
R	Warbling Vireo	1	0	1	0	0	0	0	1
R	White-breasted Nuthatch	4	5	9	5	7	12	19	33
R	Western Bluebird	1	6	7	2	8	5	13	22
R	Western Tanager	4	4	8	6	4	7	11	25
R	Wild Turkey	1	0	1	1	0	0	0	2
R	Western Wood-pewee	0	0	0	1	1	1	2	3
R	Yellow-rumped Warbler	3	4	7	2	3	4	7	16

Species	Total No. Detections	Cottonwood/Willow 55	45	35	25	15	5	Mean	Mesquite (bordering Cottonwood/Willow) 5	15	25	35	45	55	65	75	85	95	Mean
Nathalis iole	128		0.78	1.17	1.50	2.58	0.75	1.13	0.36	0.78	0.22	0.08	0.17	0.56	0.67	0.67		0.78	0.43
Unknown blue	29		1.00	0.42	0.50	0.08		0.33						0.33		0.11			0.04
Danaus gilippus	19		0.56	0.50	0.08			0.19	0.18			0.08				0.11			0.04
Eurema nicippe	18		0.11		0.17	0.33	0.08	0.12		0.22	0.22			0.22				0.11	0.08
Battus philenor	17		0.11	0.17	0.42	0.08	0.08	0.14	0.09					0.11	0.11			0.11	0.04
Pieris protodice	15					0.08		0.01					0.08	0.33				0.11	0.05
Apodemia palmerii	11		1.22					0.20											0.00
Phoebis sennae	9	0.33	0.11		0.08	0.08		0.10				0.17							0.02
Brephidium exile	9			0.08		0.08		0.03										0.11	0.01
Eurema mexicanum	8					0.08		0.01		0.33		0.08						0.22	0.06
Hemiargus isola	8		0.33	0.17	0.25			0.13											0.00
Chlosyne lacinia	5					0.08		0.01								0.11			0.01
Leptotes marina	5		0.33		0.08	0.08		0.08											0.00
Unknown skipper	4							0.00			0.11								0.01
Colias cesonia	3							0.00					0.08						0.01
Colias eurytheme	3		0.11		0.08			0.03											0.00
Vanessa cardui	3						0.08	0.01	0.09										0.01
Pholisora catullus	2			0.08				0.01											0.00
Dione vanillae	2							0.00											0.00
Ministrymon leda	2		0.11		0.08			0.03											0.00
Danaus plexippus	2			0.08				0.01											0.00
Euptoieta claudia	2		0.11					0.02											0.00
Limenitis archippus	2		0.11			0.08		0.03											0.00
Adelpha bredowii	1							0.00											0.00
Hemiargus ceraunus	1			0.08				0.01											0.00
Copaeodes aurantiacus	1							0.00											0.00
Precis nigrosuffusa	1							0.00	0.09										0.01
Texola elada	1							0.00					0.08						0.01
Libytheana carinenta	1			0.08				0.01											0.00
Asterocampa clyton	1			0.08				0.01											0.00
Eurema proterpia	1					0.08		0.01											0.00
Total Number Individuals	314	0.33	5.00	2.92	3.25	3.75	1.00	2.71	0.79	1.33	0.55	0.42	0.42	1.56	0.78	1.00	0.00	1.44	0.83
Species Richness	30	0.33	2.00	1.75	1.58	1.83	0.67	1.36	0.71	0.89	0.44	0.42	0.42	1.00	0.56	0.67	0.00	1.00	0.61

Appendix IIa. For Boquillas Ranch West (Area 1), the total number of detections as well as the average number of individuals of each species encountered at each distance from the edge for Cottonwood/Willow - Mesquite edges. Blanks indicate no individual of that species was ever encountered at that distance.

Species	Total No. Detections	Mesquite (Bordering Desert Scrub) 95	85	75	65	55	45	35	25	15	5	Mean	Desert Scrub 5	15	25	35	45	55	65	75	85	95	Mean
Nathalis iole	128	0.17	0.67		0.17		0.33				0.17	0.15											0.00
Unknown blue	29				0.33							0.03						0.17		0.17			0.03
Danaus gilippus	19			0.17								0.02		0.17	0.17								0.03
Eurema nicippe	18			0.17	0.17							0.03	0.17										0.02
Battus philenor	17							0.17			0.17	0.03		0.17									0.02
Pieris protodice	15	0.17	0.17		0.33			0.33			0.17	0.12				0.17				0.17			0.03
Apodemia palmerii	11											0.00											0.00
Phoebis sennae	9			0.17								0.02					0.17			0.17			0.03
Brephidium exile	9	0.17	0.17								0.17	0.05							0.33	0.17			0.05
Eurema mexicanum	8	0.17										0.02											0.00
Hemiargus isola	8											0.00											0.00
Chlosyne lacinia	5		0.17		0.17						0.17	0.05											0.00
Leptotes marina	5											0.00											0.00
Unknown skipper	4								0.17			0.02						0.17				0.17	0.03
Colias cesonia	3											0.00					0.17		0.17				0.03
Colias eurytheme	3											0.00						0.17					0.02
Vanessa cardui	3											0.00									0.17		0.02
Pholisora catullus	2											0.00							0.17				0.02
Dione vanillae	2	0.17		0.17								0.03											0.00
Ministrymon leda	2											0.00											0.00
Danaus plexippus	2				0.17							0.02											0.00
Euptoieta claudia	2											0.00						0.17					0.02
Limenitis archippus	2											0.00											0.00
Adelpha bredowii	1											0.00									0.17		0.02
Hemiargus ceraunus	1											0.00											0.00
Copaeodes aurantiacus	1						0.17					0.02											0.00
Precis nigrosuffusa	1											0.00											0.00
Texola elada	1											0.00											0.00
Libytheana carinenta	1											0.00											0.00
Asterocampa clyton	1											0.00											0.00
Eurema proterpia	1											0.00											0.00
Total Number Individuals	314	0.84	0.67	0.67	1	0	0.33	0.34	0.17	0	0.83	0.48	0.17	0.33	0.17	0.17	0.34	0.67	0.5	0.5	0.33	0.17	0.33
Species Richness	30	0.84	1.17	0.67	1.33	0	0.5	0.5	0.17	0	0.83	0.60	0.17	0.33	0.17	0.17	0.34	0.67	0.67	0.67	0.33	0.17	0.37

Appendix IIb. For Boquillas Ranch West (Area 1), the total number of detections as well as the average number of individuals of each species encountered at each distance from the edge for Mesquite - Desert Scrub edges. Blanks indicate no individual of that species was ever encountered at that distance.

Species	Total No. Detections	Cottonwood/Willow									Mesquite (bordering Cottonwood/Willow)						
		75	65	55	45	35	25	15	5	Mean	5	15	25	35	45	55	Mean
Pieris protodice	219									0.00	0.42	2.08	1.17	1.17	1.25	6.67	2.13
Colias eurytheme	128	0.67		0.33	1.08	0.67	1.00	1.67	0.25	0.71	0.33	0.92	1.08	1.25	1.08	0.67	0.89
Brephidium exile	70									0.00				1.00	4.42		0.90
Unknown blue	44						0.08			0.01	0.17		0.17	0.67	0.83		0.31
Danaus gilippus	38					0.17		0.08	0.08	0.04	0.25	0.17	0.33	0.67	0.33	0.67	0.40
Eurema nicippe	38				0.25	0.25	0.08	0.17		0.09	0.08	0.08	0.42	0.33	0.67	0.33	0.32
Eurema mexicanum	34			0.67	0.08		0.58		0.08	0.18	0.58	0.25	0.17	0.25	0.33		0.26
Phoebis sennae	28					0.08				0.01		0.42	0.33	0.42	0.08	0.67	0.32
Battus philenor	27	0.33			0.17			0.17	0.08	0.09	0.33	0.33	0.42	0.17		0.33	0.26
Chlosyne lacinia	24						0.08			0.01	0.50	0.33	0.33	0.33	0.25		0.29
Eurema proterpia	16				0.17	0.08	0.17	0.42	0.08	0.11			0.17		0.08		0.04
Leptotes marina	14					0.08		0.08		0.02			0.08	0.33	0.25		0.11
Copaeodes aurantiacus	14									0.00		0.25	0.33	0.33		0.33	0.21
Hemiargus isola	8									0.00							0.00
Euptoieta claudia	8							0.08		0.01	0.08	0.08				0.33	0.08
Colias cesonia	7					0.08				0.01	0.08				0.17		0.04
Strymon melinus	7				0.08					0.01				0.17	0.17	0.33	0.11
Libytheana carinenta	5					0.08	0.08			0.02							0.00
Hemiargus ceraunus	4									0.00							0.00
Pyrgus communis	4									0.00			0.08		0.08		0.03
Apodemia palmerii	4									0.00				0.25	0.08		0.06
Unknown skipper	4									0.00						0.33	0.06
Unknown metalmark	3				0.08			0.08		0.02	0.08						0.01
Vanessa cardui	3	0.33								0.04		0.08					0.01
Everes comyntas	2						0.08			0.01					0.08		0.01
Nathalis iole	2					0.08				0.01							0.00
Plebejus acmon	1									0.00					0.08		0.01
Adelpha bredowii	1									0.00	0.08						0.01
Eurema boisduvalianum	1									0.00				0.08			0.01
Pholisora catullus	1									0.00							0.00
Urbanus dorantes	1									0.00				0.08			0.01
Calephelis nemesis	1									0.00				0.08			0.01
Unknown Hairstreak	1							0.08		0.01							0.00
Euptoieta hegesia	1									0.00							0.00
Apodemia mormo	1									0.00				0.08			0.01
Texola elada	1									0.00						0.33	0.06
Limenitis archippus	1									0.00				0.08			0.01
Anteos maerula	1									0.00	0.08						0.01
Total Number Individuals	767	1.00	0.00	0.67	1.00	1.08	1.17	1.17	0.58	0.83	2.00	2.75	2.83	4.67	3.67	5.00	3.49
Species Richness	34	1.33	0.00	1.00	1.92	1.58	2.17	2.84	0.58	1.43	3.09	5.00	5.09	7.75	10.25	11.00	7.03

Appendix IIc. For San Pedro House (Area 2), the total number of detections as well as the average number of individuals of each species encountered at each distance from the edge for Cottonwood/Willow - Mesquite edges. Blanks indicate no individual of that species was ever encountered at that distance.

Species	Total No. Detections	Mesquite (bordering Desert Scrub) 45	35	25	15	5	Mean	Desert Scrub 5	15	25	35	45	55	65	75	85	95	Mean
Pieris protodice	219	5.29	2.57	3.57	1.43	1.29	2.83	1.57	0.29	0.57	0.14	0.14	0.57	0.29		0.67		0.42
Colias eurytheme	128	0.14	0.29	0.14	0.14	0.14	0.17	0.14			0.57							0.07
Brephidium exile	70				0.14		0.03	0.14	0.43									0.06
Unknown blue	44	0.29	0.43	0.14	0.29	0.29	0.29		0.29	0.14	0.29		0.14	0.14		0.67	0.67	0.23
Danaus gilippus	38	0.29	0.29	0.43	0.14	0.14	0.26				0.14				0.14			0.03
Eurema nicippe	38	0.29		0.29			0.11	0.14	0.14				0.14	0.14		0.33		0.09
Eurema mexicanum	34		0.14	0.14	0.29		0.11											0.00
Phoebis sennae	28	0.29	0.29	0.43			0.20					0.14		0.14		0.33		0.06
Battus philenor	27	0.29			0.14	0.14	0.11		0.14									0.01
Chlosyne lacinia	24		0.14				0.03		0.14									0.01
Eurema proterpia	16				0.14		0.03						0.14					0.01
Leptotes marina	14	0.14					0.03	0.14							0.29			0.04
Copaeodes aurantiacus	14		0.14			0.14	0.06											0.00
Hemiargus isola	8						0.00	0.14	0.14		0.14		0.14	0.14	0.29	0.33		0.13
Euptoieta claudia	8			0.14			0.03		0.14		0.14		0.14					0.04
Colias cesonia	7	0.29					0.06		0.14									0.01
Strymon melinus	7				0.14		0.03											0.00
Libytheana carinenta	5					0.14	0.03		0.14	0.14								0.03
Hemiargus ceraunus	4						0.00					0.43			0.14			0.06
Pyrgus communis	4						0.00							0.14		0.33		0.05
Apodemia palmerii	4						0.00											0.00
Unknown skipper	4	0.14				0.14	0.06						0.14					0.01
Unknown metalmark	3						0.00											0.00
Vanessa cardui	3						0.00	0.14										0.01
Everes comyntas	2						0.00											0.00
Nathalis iole	2						0.00								0.14			0.01
Plebejus acmon	1						0.00											0.00
Adelpha bredowii	1						0.00											0.00
Eurema boisduvalianum	1						0.00											0.00
Pholisora catullus	1			0.14			0.03											0.00
Urbanus dorantes	1						0.00											0.00
Calephelis nemesis	1						0.00											0.00
Unknown Hairstreak	1						0.00											0.00
Euptoieta hegesia	1				0.14		0.03											0.00
Apodemia mormo	1						0.00											0.00
Texola elada	1						0.00											0.00
Limenitis archippus	1						0.00											0.00
Anteos maerula	1						0.00											0.00
Total Number Individuals	767	2.92	2.50	2.17	1.96	1.59	2.23	1.59	1.67	0.46	1.09	0.38	1.29	0.88	0.75	2.33	0.67	1.11
Species Richness	34	7.29	4.38	5.79	3.17	2.46	4.62	2.54	2.09	0.96	1.46	0.63	1.46	1.04	1.09	2.67	0.67	1.46

Appendix IId. For San Pedro House (Area 2), the total number of detections as well as the average number of individuals of each species encountered at each distance from the edge for Mesquite - Desert Scrub edges. Blanks indicate no individual of that species was ever encountered at that distance.

Species	Total No. Detections	Cottonwood/Willow								Sacatone Grassland										
		65	55	45	35	25	15	5	Mean	5	15	25	35	45	55	65	75	85	95	Mean
Colias eurytheme	171	0.67	0.67	1.33	1.00	0.75	0.42	0.42	0.75	0.75	0.67	0.75	1.42	0.67	1.25	1.00	1.83	0.83	0.83	1.00
Pyrgus communis	151	0.50	0.17	0.44	0.42	0.42	0.08	0.25	0.33	1.08	1.42	1.83	1.33	2.17	0.50	0.17	0.83	0.58	0.83	1.08
Pieris protodice	47		0.17		0.25				0.06	0.17	0.33	0.67	1.00		0.25	0.42	0.17	0.33	0.25	0.36
Phoebis sennae	31	0.67	0.17		0.58				0.20	0.17	0.33		0.25	0.08	0.08	0.25	0.25	0.08	0.08	0.16
Eurema mexicanum	27	0.17	0.33	0.22	0.42	0.50	0.17	0.33	0.31	0.08	0.17						0.17			0.04
Danaus gilippus	26		0.33	0.11	0.50	0.25		0.17	0.19	0.17	0.17	0.08	0.17	0.08		0.08	0.25			0.10
Chlosyne lacinia	24		0.17		0.08				0.04	0.17	0.17	0.75	0.33	0.08		0.08	0.08		0.17	0.18
Unknown blue	22	0.17	0.33	0.33	0.25	0.33	0.33	0.08	0.26			0.08		0.08	0.08			0.08		0.03
Battus philenor	19	0.17	0.17		0.08	0.08	0.25		0.11	0.08	0.17	0.08	0.17			0.17	0.17		0.17	0.10
Eurema proterpia	15	0.17	0.50	0.33	0.25	0.17		0.08	0.21	0.08						0.08				0.02
Brephidium exile	11								0.00		0.08	0.42	0.08	0.17	0.08				0.08	0.09
Calephelis nemesis	9		0.17	0.11	0.25		0.33		0.12											0.00
Strymon melinus	8	0.17			0.08	0.25			0.07	0.25										0.03
Eurema nicippe	8		0.33		0.17	0.17			0.10	0.08						0.08				0.02
Euptoieta claudia	4			0.11			0.08		0.03		0.08				0.08					0.02
Calephelis arizonensis	3			0.11			0.08		0.03	0.08										0.01
Eurema boisduvalianum	3			0.11	0.08		0.08		0.04											0.00
Colias cesonia	3								0.00		0.08	0.08							0.08	0.03
Nathalis iole	3								0.00	0.08	0.08						0.08			0.03
Vanessa cardui	3								0.00		0.08		0.08	0.08						0.03
Asterocampa clyton	3					0.25			0.04											0.00
Unknown skipper	2		0.17						0.02	0.08										0.01
Ministrymon leda	1					0.08			0.01											0.00
Leptotes marina	1								0.00					0.08						0.01
Libytheana carinenta	1								0.00	0.08										0.01
Total Number of Individuals	596	1.67	2.84	1.78	2.92	1.84	0.92	0.75	1.81	2.17	2.25	2.34	2.50	1.42	1.17	1.42	2.00	1.33	1.67	1.82
Species Richness	24	2.67	3.67	3.22	4.42	3.25	1.84	1.33	2.91	3.42	3.83	4.75	4.84	3.50	2.33	2.42	3.84	1.92	2.50	3.33

Appendix IIe. For South San Pedro (Area 3), the total number of detections as well as the average number of individuals of each species encountered at each distance from the edge for Cottonwood/Willow - Sacatone edges. Blanks indicate no individual of that species was ever encountered at that distance.

Appendix IIIa. Species detected during surveys of edges between restored and unrestored ponderosa pine forest at Mount Trumbull. The number of detections for each species is reported for the forest, edge, and unrestored dense forest, as well as the total count for each species. This data represents three rounds of surveys.

Species	Number of Detections							
	Forest			Edge	Natural Meadow			Total Count
	-200	-100	Subtotal	0	100	200	Sub-total	by species
*Blue spp.**	14	9	23	17	26	23	49	89
Colias eurytheme	6	2	8	9	11	12	23	40
*Crescent spp.**	1	0	1	2	1	2	3	6
Danaus gliippus strigosis	0	0	0	0	1	0	1	1
Epargyreus clarus	0	1	1	2	1	0	1	4
Euphydryas chalcedona	1	0	1	1	2	0	2	4
Euptoieta claudia	2	1	3	2	1	3	4	9
Hypaurotis crysalus crysalus	1	0	1	0	0	0	0	1
Leptotes marina	0	0	0	1	1	1	2	3
Liminitis bredowii	5	8	13	5	1	1	2	20
Liminitis weidemeyerii	1	1	2	2	0	1	1	5
Nathalis iole	0	0	0	0	2	1	3	3
Papilio multicaudata	0	2	2	1	0	1	1	4
Phyciodes campestris	4	0	4	0	0	0	0	4
Pieris protodice	0	0	0	0	9	5	14	14
Plebejus acmon	1	1	2	0	5	0	5	7
Polygonia gracillus	0	0	0	3	2	1	3	6
Precis coenia	0	0	0	0	2	0	2	2
Pyrgus communis	1	0	1	2	2	2	4	7
*Skipper spp.**	2	2	4	7	6	4	10	21
Strymon melinus	1	1	2	2	5	1	6	10
Vanessa cardui	1	0	1	0	8	0	8	9
*Vanessa spp.**	0	0	0	2	1	2	3	5

*See Appendix IIIc for a list of possible species.

Appendix IIIb. A list of the species detected during surveys of natural edges in ponderosa pine forest at Camp Navajo. The number of detections for each species is reported for the forest, edge, and natural meadow, as well as the total count for each species. This data represents five rounds of surveys.

Species	Number of Detections							
	Forest			Edge	Natural Meadow			Total Count
	-200	-100	Subtotal	0	100	200	Subtotal	by species
*Blue spp.**	16	22	38	24	34	16	50	112
Colias eurytheme	4	5	9	28	20	21	41	78
*Crescent spp.**	1	5	6	4	1	1	2	12
Danaus gliippus strigosis	0	0	0	1	0	0	0	1
Epargyreus clarus	0	2	2	0	0	0	0	2
Euptoieta claudia	0	1	1	4	16	16	32	37
Glaucopsyche lygdamus	1	1	2	6	1	1	2	10
Liminitis bredowii	1	1	2	2	0	0	0	4
Nathalis iole	13	3	16	16	7	11	18	50
Neophasia menapia	6	5	11	4	3	6	9	24
Oarisma garita	2	2	4	3	2	3	5	12
Phyciodes campestris	4	0	4	1	1	0	1	6
Pieris protodice	2	2	4	3	6	4	10	17
*Pieris spp.**	2	1	3	3	4	6	10	16
Plebejus acmon	4	6	10	12	9	9	18	40
Precis coenia	0	0	0	0	2	0	2	2
Pyrgus communis	0	1	1	2	2	3	5	8
*Skipper spp.**	5	5	10	4	5	3	8	22
Strymon melinus	4	1	5	3	1	3	4	12
Vanessa carye	0	0	0	2	1	0	1	3
*Vanessa spp.**	0	2	2	2	2	2	4	8

*See Appendix IIIc for a list of possible species.

Appendix IIIc. A list of probable species for butterflies that were identified to genus or higher taxonomic order.

Temporary ID:	Possible species:
Blue spp.	*Hemiargos isola*
	Leptotes marina
	Plebejus melissa
	Plebejus saepiolus
	Plebejus acmon
	Strymon Melinus
Crescent spp.	*Chlosyne leanira fulvia*
	Euphydryas chalcedona
	Polydryas minuta
Pieris spp.	*Pieris napi*
	Pieris protodice
	Pieris sysynbrii
Vanessa spp.	*Vanessa cardui*
	Vanessa carye